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LACV-30 AUXILIARY POWER UNIT INVESTIGATION

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

An investigation was performed to determine the cause and solution to a series of Auxiliary Power Unit (APU) failures on LACV-30 vehicles. Vibration and other measurements were made on the complete installation, the APU module alone and the engine alone. It was concluded that the APU module arrangement reinforced or excited an engine vibration mode to destructive amplitudes. The problem was solved by modifying the APU to virtually eliminate this vibration.

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SUMMARY

This report documents the results of an intensive investigation to determine the cause of a series of T-62T-32-3 engine failures in the Auxiliary Power Unit (APU) on the LACV-30 vehicles, and to develop a solution to the problem.

Failure investigations were performed on failed engines S/N's 750186, 750207 and 750185, all from LACV-30-1. Study of the failed hardware yielded no significant results. An examination was made of the engine build histories and rotor clearance records, also without significant results.

Vibration measurements were made on engine S/N 750185, just prior to failure. The measurements showed levels of 250 and 1000 Hz vibrations generally similar to those which had been measured on engine S/N 500056 during initial LACV-30-1 checkout tests in January, 1976.

Similar measurements were made on five well-performing engines of the same type in Army Ground Power Units at Fort Belvoir. Only one engine showed the presence of 250 Hz vibration, and that was at a low level.

The first of a series of extensively instrumented tests was performed on LACV-30-2 at Aberdeen Proving Grounds, on engine S/N 750192 which had accumulated 260 hours of operation. No unusual vibration characteristics were noted in any mode of operation. Significantly, the 250 Hz vibration previously seen on engines which later failed was of very small magnitude, and was discernible only by using a Peak Hold capability of the spectrum analyzer.

A replacement engine (S/N 750228) for LACV-30-1 was specially instrumented with thermocouples on the roller bearing and with proximity probes reading the motion of the aluminum structure surrounding the bearing support tube. This engine was acceptance tested at Solar on their production test stand and produced a normal vibration signature. The engine was then transferred to Alturdyne where it was installed in the APU module. During testing in this module, it was found that the rotor first flexure mode of vibration (~ 250 Hz) was at an abnormally high level. It was calculated that the roller bearing loading resulting from the measured displacement would drastically reduce bearing life. It was also found that this vibration could be controlled by the application of very light loads on the combustor discharge flange or by the installation of an exhaust bellows or heavy tailpipe.

A reinforced panel to attach an exhaust bellows to the module structure was fabricated and tested, with the result that the flexure mode was controlled to very low magnitude. This unit was then tested aboard LACV-30-1 at Fort Story, Virginia. No phase of craft operation was found to excite the vibration to significant levels with the panel and bellows in place.

During the test program, the instrumented engine was operated on Solar's test stand without any exhaust pipe connection, and the 250-Hz mode was not excited to significant levels. The same engine was tested in the APU module (without bellows) immediately following this test and experienced 5-mil excursions. A second T-62T-32 (S/N 700097) in an EMU-30/E generator set was tested with no exhaust system connected and the test results corroborated the Solar production test stand results.

It was concluded from this investigation that the inherent first rotor flexural mode of the engine was being reinforced or excited to destructive levels in the original APU module configuration and that this vibration could be controlled to acceptable levels by modification of the APU.

As of June 1, 1977, the modified APU aboard LACV-30-1 had accumulated 380 hours of successful operation. In March, 1977, an unmodified APU aboard LACV-30-2 (engine S/N 750192) failed after 310 hours of operation. Both vehicles now have modified APU's, and cabin instruments to continuously monitor the 250-Hz mode of vibration.

PREFACE

This report documents the results and conclusions of a joint U.S. Army/Bell/Solar/Alturdyne investigation of the cause and solution to a series of APU engine failures on the LACV-30 vehicles. The formal investigation was initiated in September, 1976 and completed prior to acceptance by the Army of the second vehicle in January, 1977. APU operating experience to date is included in this report.

The contributions to the investigation of the following personnel and organizations is gratefully acknowledged:

Mr. John Sargent, C.O.T.R.
U.S. Army Mobility Equipment Research and Development Command

Mr. Norman Travis, Project Engineer
Alturdyne

Mr. Douglas Martin, Project Engineer
Solar Division of International Harvester Company.

Acknowledgement is also made of the direct and indirect use in this report of material from Alturdyne and Solar reports and related correspondance between these organizations and Bell Aerospace Textron.

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ILLUSTRATIONS

TABLES

I. INTRODUCTION

The LACV-30 Air Cushion Lighter employs an Auxiliary Power Unit (APU) to supply 30 kilowatts of electrical power and to drive a 90 horsepower fan used in the inlet Air Management System (AMS). A Solar T-62T-32-3 gas turbine engine is used as the prime mover. The engine is packaged in an enclosure with a starter, alternator and secondary reduction gearbox, by Alturdyne. The enclosure and its internal arrangement is shown in Figure 1. The system is installed on the two lead vehicles: LACV-30-1 and -2. The original installation configuration is shown in Figure 2.

The APU's on both vehicles failed in January, 1976 during early checkout operations at Bell Aerospace Textron facilities. (A list of the failure incidents which occurred prior to the completion of the investigation is given in Table 1.) Following tear-down inspection by Solar, both failures were attributed to foreign object damage. Modifications to the system were incorporated to prevent re-occurance; the modified installation is shown in Figure 3.

TABLE 1
APU FAILURE HISTORY

Date 1976	Vehicle Location	Engine Hours	Failed Thrust Bearing	Failed Roller Bearing	Sheared Bearing Support	Shed Blades	Failure Attributed To
1/26	-002 Grand Bend	750155 8		X	X	X	F.O.D.
1/28	-001 Wheatfield	500056 56		X	X	X	F.O.D.
4/13	-001 Ft. Story	750185 20	X				Quality Control Overload
8/28	-001 Ft. Story	750186 78	X				Quality Control Overload
8/31	-001 Ft. Story	750207 4 Min.		X	X	X	Roller Bearing
9/27	-001 Ft. Story	750185 22		X	X	X	Roller Bearing

No further failures were experienced on LACV-30-2 prior to the conclusion of the study.* The replacement engine (S/N 750192) had accumulated some 260 hours of operation at that time.

The replacement engine (S/N 750185) on LACV-30-1 failed in April, 1976 after 20 hours of operation. The failure mode was markedly different than the previous failures, and was attributed to quality control in the thrust bearing. In August, 1976 after 78 hours of operation, the next replacement engine (S/N 750186) also experienced a thrust bearing failure, which again was attributed to quality control. When the next replacement engine (S/N 750207) failed after four minutes of operation, however, it became clear that a thorough investigation of the problem was required.

An intensive inspection of the most recently failed engines and of the build-up of the replacement engine was immediately initiated. At the same time, a preliminary plan for extensive test and analysis was developed for review with MERADCOM personnel on September 29, 1976. Another

*The LACV-30-2 APU eventually failed in March, 1977. See Section V.

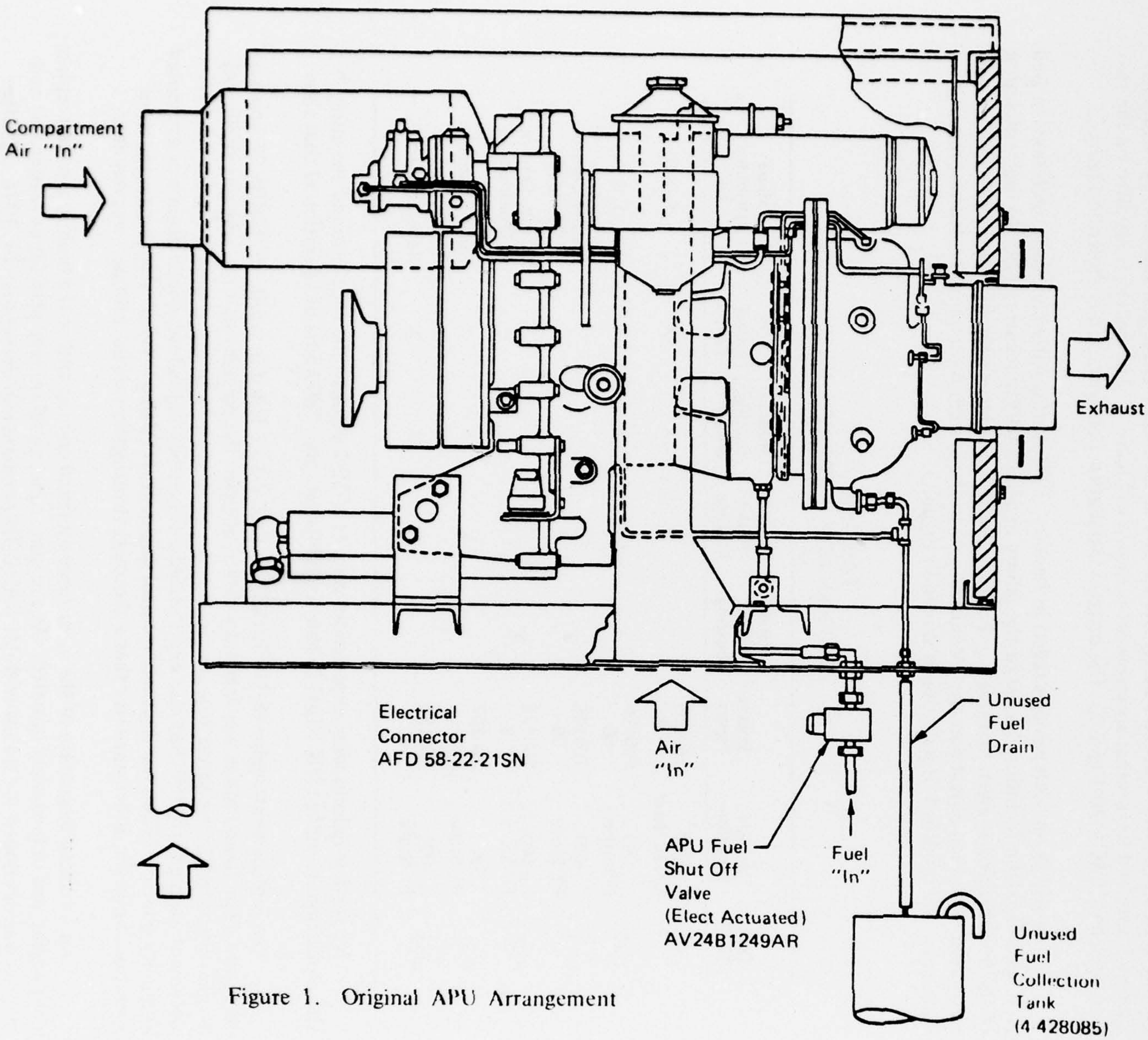


Figure 1. Original APU Arrangement

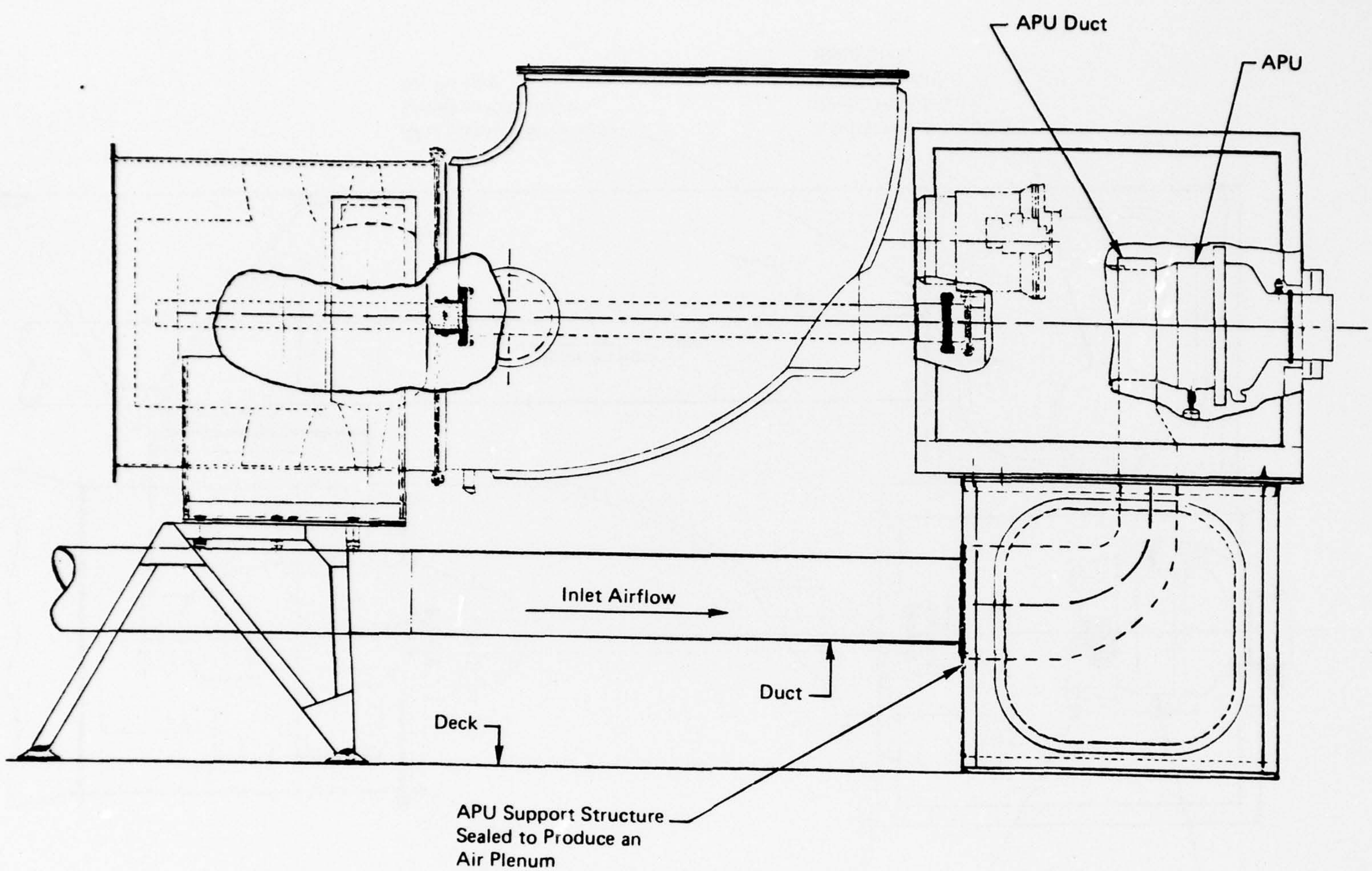
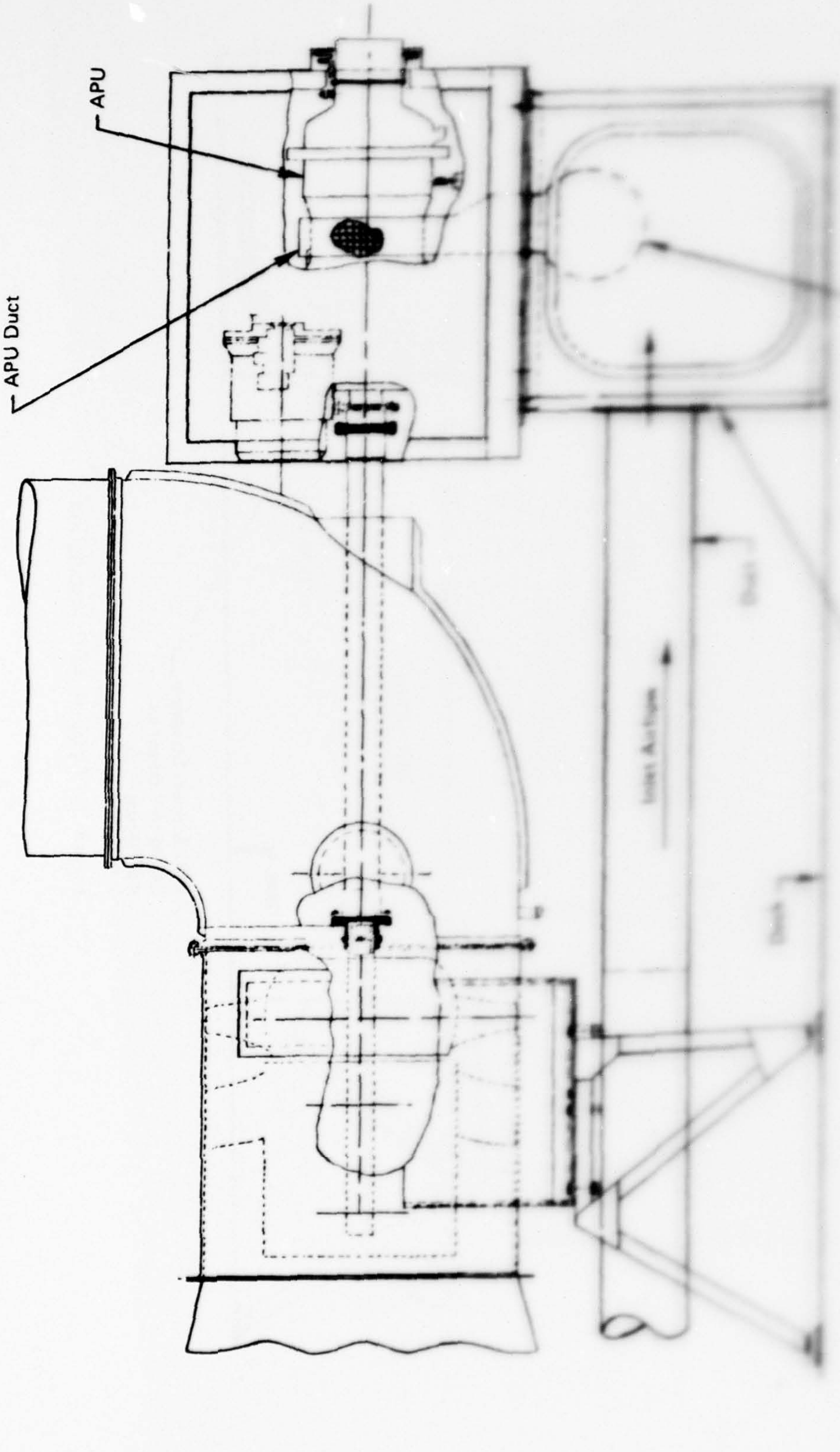


Figure 2. Original APU Installation


APU
APU Duct
Inlet Airflow

APU failure (S/N 750185) on September 27, the last to occur on LACV-30-1, gave added impetus to the investigation.

II. PLAN OF INVESTIGATION

After the August 1976 APU failures, plans were immediately made for thorough teardown inspections and careful build-up of the replacement units, in the presence of Army, Bell, Alturdyne, and Solar representatives. The inspection of S/N 750186, as all previous inspections, was confined to the engine itself. The enclosure and all accessories had remained with the vehicle to be used with a replacement engine. Recognizing that all APU failures except the first had occurred on the same vehicle, with the same gearbox and accessories, the entire enclosure was returned to Alturdyne for inspection following the failure of S/N 750207.

The work statement for the return to service of the APU assembly (Alturdyne P/N 128-105590, S/N 114-1) with replacement engine S/N 750185, is presented in Appendix A. It is seen that considerable emphasis was placed on oil cleanliness and free passage: prior inspections of failed engines had noted evidence of insufficient lubrication.

Suspicion had also been directed toward the shaft and coupling connecting the APU to the AMS fan, as possibly transmitting excessive axial loads to the APU. It was planned to monitor APU vibration after re-installation on the LACV-30-1 at Fort Story, both before installation of the connecting shaft and after carefully aligned installation.

On September 19, 1976, Bell met with MERADCOM personnel to formulate an approach to a thorough investigation of the problem. An important consideration at this meeting was the fact that more than 1400 of the same type Solar T-62T-32-3 engines had operated for almost half a million hours with no more than 25 bearing failures over a span of two years. The Army itself had used 35 such engines for the Patriot missile system, in ground-based power supplies, with good reliability. This strongly suggested that the LACV-30-1 problem was one of installation or application. Counter to this, however, was the fact that the APU aboard the nearly identical LACV-30-2 had a accumulated more than 200 hours of successful operation, following the initial failure attributed to foreign object damage.

Consideration was also given to various "theories" which had been advanced as possible contributors to the failures. In addition to the previously mentioned foreign object ingestion, bearing quality control, oil contamination and fan shaft axial forces, the possibilities included:

1. Oil cooler efficiency. Excessive oil temperatures may be being suppled to the engine.

2. External vibration and acoustic environment. The APU is located at the stern of the vehicle in the proximity of the propellers and the lift fans.

3. Pressurized air intake. Filtered air is provided to the APU from the vehicle's Air Management System, at a pressure some 10 inches of water (52 psf) above ambient. Also, operation of the AMS fan in stall may cause pressure pulsations. These conditions, not encountered in other applications, could conceivably affect rotor thrust loads and lubrication flows.

4. Structural resonance. The APU enclosure or mounting structure may be resonant at an engine frequency, thus magnifying vibration amplitudes to destructive levels.

5. Starting load. The AMS fan is directly coupled to the engine, imposing an inertial and aerodynamic load during starting. These loads had been considered and found acceptable during the system design, but they represent a departure from other applications.

6. Overhanging alternator mass. The alternator mounting arrangement in this installation is atypical, and may produce a bending moment on the gearbox and engine casing.

7. Engine mounts. The engine mounting includes redundancies which may prevent thermal growth or vehicle bending stresses from being relieved.

8. Shipping damage. Shock loads could cause the overhung rotor to damage bearings and thus account for early failure of units which had been carefully built-up and satisfactorily operated at Alturdyne.

It was agreed that an extensive test program would be performed.

Key aspects of the program were:

1. Direct participation by Solar and Alturdyne, with Bell coordinating.

2. Instrumentation to include thermocouples, accelerometers, microphones and pressure transducers to address possible problem items 1 through 4 above, and a strain gage on the aft engine mounting link to address both item 7 and the possibility that the AMS fan may be applying axial loads on the engine. A recording accelerometer was to be shipped with the replacement APU to address item 8.

3. Testing to be performed with identical equipment, first on the successfully operating APU aboard the LACV-30-2 to establish a baseline, and then on the replacement APU for LACV-30-1.

4. Vibration testing also to be performed on the replacement APU after build-up at Alturdyne, and on Army ground power units using similar engines at Ft. Belvoir.

The complete work statement for this investigation is presented in Appendix A.

III. RESULTS OF THE INVESTIGATION

PRELIMINARY INVESTIGATIONS

The teardown inspection of engine S/N 750186 and of the complete APU with engine S/N 750207 was accomplished from September 8 to 15, 1976. A detailed report of the findings is presented in Appendix D, along with a listing of the Army, Bell, Alturdyne and Solar personnel witnessing the inspection. No clear conclusion as to the actual cause of failures was reached.

The buildup of the replacement APU with engine S/N 750185 was accomplished according to the plan of Appendix A. This unit arrived at Fort Story on September 21. Installation, including accurate alignment with the fan shaft, was completed the next day. Bell instrumented the APU with three-axis accelerometers mounted on the top of the engine inlet housing (at the turbine flange) and on one of the forward mounts. On September 24, vibration measurements were made with the fan shaft connected and disconnected. Measured g-levels are listed in Table 2. They are generally similar to levels which had been measured on engine S/N 500056 during initial checkout tests on LACV-30-1 in in January, 1976.

TABLE 2
ENGINE S/N 750185 VIBRATION MEASUREMENTS

Vehicle: LACV-30-1 Location: Fort Story, VA. Date: September 24, 1976		Fan Shaft Connected		Shaft Disconnected	
		1000 Hz	250 Hz	1000 Hz	250 Hz
Turbine Flange	- Vertical	11.8g	7.8g	-	13.4g
	- Lateral	8.6	12.8	-	17.2
	- Longitudinal	12.0	7.0	-	7.5
Forward Mount	- Vertical	9.4	1.0	10.0g	1.6
	- Longitudinal	10.0	1.5	11.5	0.7

The significance of the observed vibration at 250 Hz, which reached transient levels as high as 17 g's, was not recognized at that time. It is noted, however, that this engine failed within five operating hours after these tests. Table 2 also shows that the vibration levels were usually somewhat lower with the fan shaft connected than with it disconnected.

During the week of October 18, 1976, engine S/N 750185 was disassembled at Alturdyne with full representation from Solar, Alturdyne, and Bell. The turbine section was closely examined as the teardown progressed. The mode of failure was clearly a failure of the rotor roller bearing. The failure was well advanced with subsequent damage to all the rotating and stationary components. A summary of observations concerning the engine condition is presented in Table 3. As is usually the case in a failure of this severity, very little could be discerned from the failed components due to the extent of the damage.

The reduction drive assembly was also subjected to critical examination because of its involvement in all five engine failures. The primary reduction system (pinion, star gears, ring gear) was examined by Solar's gear design specialist and pronounced to be in excellent condition. There was no evidence of a gear-induced dynamics problem, which would be readily apparent in a high-speed (61,091 rpm) gear train. The carrier with star gears and the ring gear were used on the rebuild of this drive assembly. The pinion was replaced due to heat damage to the area located under the failed roller bearing. All secondary gears were also examined and were in excellent condition with normal tooth mesh patterns. A jig bore inspection was made of the flatness and concentricity of the carrier pilot diameter and found to be well within drawing tolerance. All oil passages were clear, and the pump was functionally checked and found to be serviceable.

Subsequent to this component inspection, a meeting was held at Solar to review all aspects of this and other failures. The entire failure investigation team was present. All conceivable failure causes

TABLE 3
ENGINE S/N 750185 TEARDOWN OBSERVATIONS

1. Turbine rotor loose in assembled housing, apparent bearing failure.
2. Aluminum metal spray from air inlet housing noted on combustor and nozzle surfaces.
3. Combustor shows no visible distress. Flame pattern normal. No indication of O-ring leakage.
4. Turbine nozzle bolts in place and lockwired. No indication of undue loads on pins. Nozzle/turbine contour heavily rubbed.
5. No visible distress on pinion major diameter. Oil dam correctly positioned. Coast side of gear shows light end-loading of teeth.
6. Slinger nut staked properly and torqued.
7. Compressor severely damaged. Two pieces of inducer shed, two torn. Heavy rubs over contour.
8. Bearing support tube end, bearing, and labyrinth sheared and trapped in compressor bore.
9. Severe damage to bearing rollers. All are burned and show flat spots.
10. Rotor shaft damaged around bearing track with heavy groove over 180 degrees.
11. Debris from failure on back face of air inlet.
12. Seal plate ID obviously rubbed from radial play on assembly.
13. Air inlet housing "milled" to contour of gyrating compressor.

were examined and courses of action proposed to eliminate these as areas of question. Included were lubrication, rotor dynamics, aerodynamics effects, contamination, propeller wake effects, quality control, and critical engine dimension combinations. A plan of action suporting the work statement was developed, and engine instrumentation was selected to examine all contingencies which might develop during testing.

One possible failure mode forwarded was failure in fatigue of the steel bearing support tube at the roller bearing shoulder. The available fracture surfaces of the tube from engine S/N 750185 were examined by the solar metallurgical group for evidence of high-cycle fatigue, with negative results. It should be noted that most of the surface had been destroyed in the failure. In retrospect, the damage noted during the failure does not support this hypothesis because a primary failure in this area would leave the bearing relatively intact with severe damage to the rotating components. All the roller bearing failures showed evidence of severe bearing/shaft damage.

The Bell representative engaged in a study of quality control procedures and engine clearance records with Solar support. A Bell quality control representative was brought in to review these areas with Solar's cognizant personnel. No significant findings with respect to the failure problem were generated by this study, either in quality control or in dimensional analysis.

TESTS AT FORT BELVOIR

On October 18, 1976, Bell measured vibration levels on five type EMU 30/EA Generator Sets, with Solar T-62T-32 engine S/N's 74-0978, -0980, -0982, -0986 and -0989, at Fort Belvoir. Vibration levels at 1E ranged from 0.05 to 0.26 mil, with the highest level measured on S/N 74-0986. Only that engine exhibited any detectable vibration at 1F, and that was at a low level.

TESTS AT ABERDEEN PROVING GROUND

The initial tests with the full instrumentation were performed on engine S/N 750192 aboard LACV-30-2 at Aberdeen Proving Ground, Maryland, on October 19, 1976. This engine had accumulated more than 260 hours of operation without failure. These tests were to establish an acceptance baseline for similar tests to be made later on LACV-30-1 at Fort Story and to discern whether any condition existed under different modes of craft operation which might contribute to the premature failure of the power unit. A test plan was generally agreed upon for the Aberdeen test, which specified that the vibration characteristics of the APU would be monitored in incremental steps from the APU alone to a full craft operational profile.

In addition to the Bell instrumentation listed in Appendix B, Solar provided vibration analysis equipment with both real-time spectrum analysis capability and recorded data playback capability. This equipment was used throughout the test program and provided continuity of results for all test locations. Solar instrumentation consisted of three uniaxial accelerometers secured on the side mount of the air inlet housing to indicate in the vertical, horizontal, and axial directions. A fourth accelerometer was mounted on the Alturdyne gearbox at the level of the output shaft to indicate in the axial direction. Speed and voice channels were also recorded. Data were read out direct on a Spectral Dynamics Spectroscope Model SD330A spectrum analyzer and was recorded for later analysis.

Data were taken with the APU running with the air management fan driven, with the craft on tether through most of its operating range, with the craft operating over water through a full flight profile, and finally with the APU disconnected from the air management fan. The most significant result of the test program was that the engine operated well within the acceptable limits of vibration for a new engine under all modes of craft operation. The first engine order (1E) mode was predominant in all cases and well within the 0.4-mil limit. The 250-Hz rotor flexural (1F) mode of vibration seen on previously failed engines was noted only by using a Peak Hold mode of the spectrum analyzer to capture the highest values of vibration and was of very small magnitude in all cases. Typical vibration signatures are included as Appendix C, Section 1. No unusual or unexpected modes were noted.

TESTS AT SOLAR

Instrumentation selected to monitor dynamic performance was the same as at Aberdeen Proving Ground with the following additions (see Figure 4):

1. **Roller Bearing Temperature Thermocouples.** These were installed in duplicate through the bearing support shoulder with the bead preloaded against the bearing race. The thermocouples were J-type (iron-constantan) 0.06-inch diameter magnesium-oxide-packed, metal-sheathed leads secured with tack-welded stainless foil.

2. **Shaft Orbit Proximity Probes.** Two probes were installed through the outer wall of the air inlet housing to sense movement at the end of the aluminum structure of the bearing support column just ahead of the impeller.

Engine S/N 750228 was supplied by Bell through Alturdyne and was modified by Solar to accept the agreed upon instrumentation. The engine was reassembled at Solar with the same components, including bearings, used on the initial build. This engine was mounted on the production acceptance test stand at Solar using the normal slave gearbox and alternator. Test oil was Mobil Jet II (a 23699 specification oil) in accordance with the decision to maintain one type of oil throughout

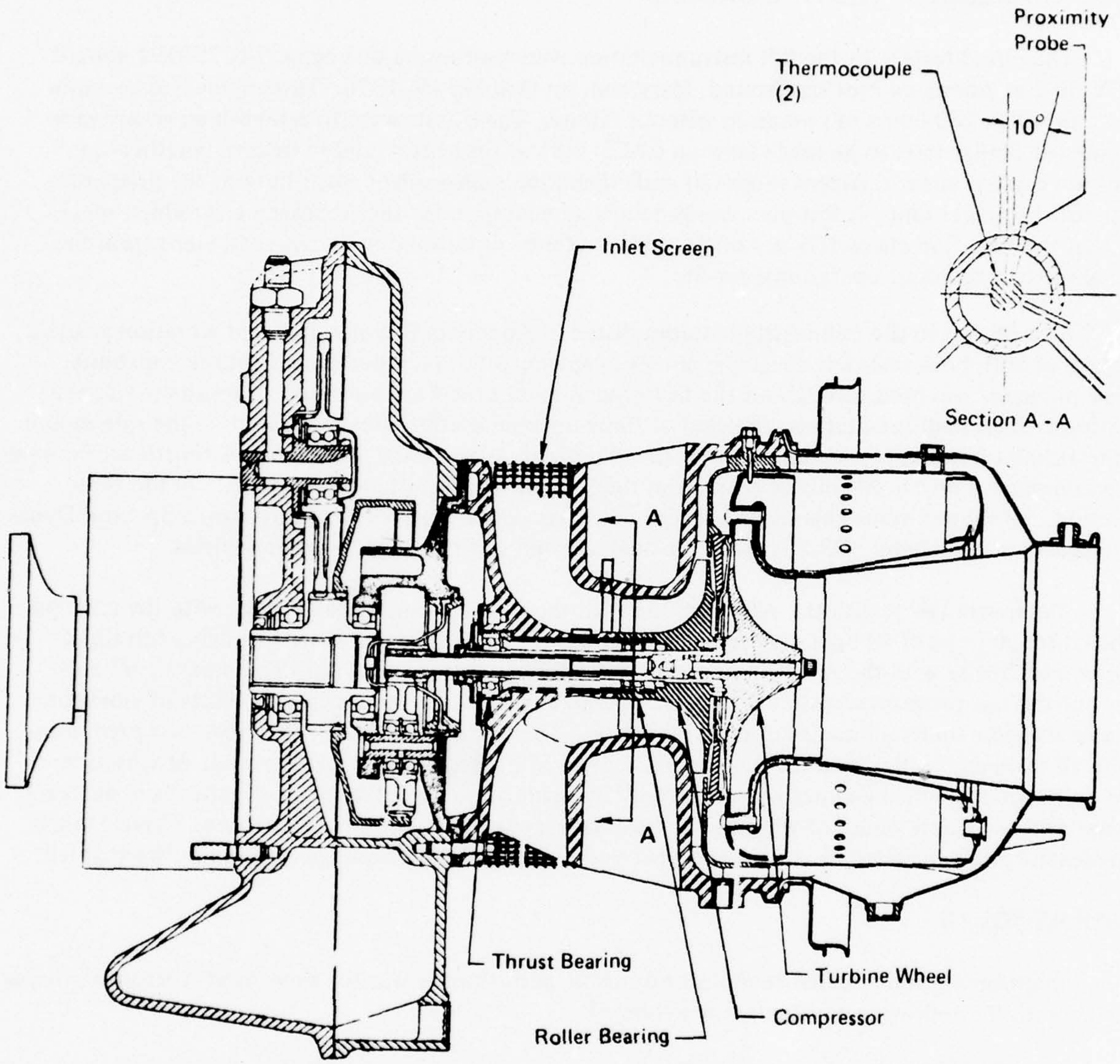


Figure 4. Internal Engine Instrumentation for Tests

the test program. The oil changeover process was the recommended fill/flush/fill procedure with the appropriate oil filter changes. An instrumented tailpipe was attached.

On October 27, 1976 vibration signature data were taken at all load points required by the acceptance test specification. Typical spectrum analyses are attached in Appendix C, Section 2. Accelerometer data indicated performance well within acceptable standards with case vibration indicating less than 0.4 mil (in fact less than 0.1 mil) at rotor frequency. Proximity probes indicated normal spectrum data with primary components in the rotor flexural (1F) and first engine order (1E) modes. the 1F mode in all cases was less than 0.5 mil peak excursion with normal levels of 0.2 to 0.3 mil. The 1E mode showed characteristic spiking between 1.0 mil peak excursions and a base level of 0.1 to 0.06 mil excursion. Peak excursions were noted using a Peak Hold capability of the spectrum analyzer, which stores the highest input over a period of samples. Sampling contained in all cases until no increase in stored signal was noted.

TESTS AT ALTURDYNE

The engine was transferred from Solar to Alturdyne and installed in the Bell module, which was secured to a channel-iron frame and aligned with a 60-Hz generator to supply shaft load. A silencer was fitted to protect personnel working in the area. On October 28, data were taken at 0, 25, 50, and 75 kW load points and under transient loading conditions. The most significant observation was a slight reduction in the 1F mode of vibration. Vibration signatures are included in Appendix C, Section 3a.

For the final test in the series, a load cell was installed in place of the aft engine mount to check for axial load transfer. To obtain readings from the load cell, it was necessary to release the bellows connection at the silencer. In fact, the silencer was removed altogether and replaced with the short tailpipe section used on the craft. The first run in this configuration resulted in a very high 1F component of vibration with peaks to 3.5 mils. A systematic program of alterations was begun to return to the previous day's configuration. This included realignment, running without the shaft, reinstallation of the hard aft mount, and, finally, reinstallation of the silencer. Only installation of the silencer reduced the 1F component to its previous low level. A series of runs was then made with engine S/N 750228 in the Bell module. Vibration signatures are presented in Appendix C, Section 3b through 3f. These are described as follows:

3b. Engine with silencer installed and driveshaft disconnected. Horizontal proximitor: 1F at 0.2 mil, 1E at 0.45 mil Peak Hold.

3c. Engine without silencer attached, driveshaft disconnected.. Horizontal proximitor: 1F at 2 mils, 1E at 0.35 mil Peak Hold.

3d. Engine without silencer or driveshaft, but loading combustor discharge flange with a 2 x 4 board: 1F at 0.5 mil, 1E at 0.46 mil Peak Hold.

3e. Engine without silencer or driveshaft, with Solar instrumented tailpipe. Horizontal proximeter: 1F at 0.2 mil, 1E at 0.6 mil Peak Hold.

3f. Engine under 75 kW load with and without damping of combustor flange with a 2 x 4. Horizontal proximitor, with damping: 1F at 0.32 mil, 1E at 0.36 mil Peak Hold; Horizontal proximitor without damping: 1F at 3.5 mils, 1E at 0.42 mil Peak Hold.

As is evident from the data presented in Section 3, it was possible to bring the rotor in and out of the high displacement 1F mode with the application of load to the combustor exhaust flange. During the high displacement mode periods, the roller bearing temperature rose approximately 30°F and returned to normal with cessation of the high-amplitude motion.

At this point in the program a decision was made to pursue the bellows approach by fabricating a rear panel for the module which allowed attachment of a flanged bellows on spacers to permit the exhaust of hot generator air from the compartment. This arrangement was tested on November 3. The bellows was found to be most effective when in compression. The results of the final configuration are presented as Section 3g of Appendix C.

RETEST AT SOLAR

The turbine section was delivered to Solar for replacement of the bearings and inspection of the engine. The engine was found to be in excellent condition with no evidence of rotor rubs or other damage. The bearings were examined by the bearing specialist and the roller bearing was noted to have polished roller ends, indicative of running misaligned with the cage. This would be expected from the large rotor orbit and subsequent misalignment of the shaft to the bearing. The thrust bearing was visually perfect.

The engine was then retested at Solar on November 5, with the results indicated in Appendix C, Section 4a. The vibration signature was much like that of the original test at Solar, except that the 1F component was more stable with less pronounced "spiking". Thus, the highest 1F level achieved was only 0.2 mil with a base of 0.06 mil. The instrumented tailpipe was removed, leaving an unsupported combustor exhaust flange to determine whether the high 1F component was a function of combustor restraint or of the installation. A very slight rise to 0.3 mil peak on the horizontal probe was noted, as shown in Section 4b of Appendix C, but nothing of the magnitude noted in the Bell module was seen.

Because of the less pronounced "spiking" and because the signature in the 1F mode was markedly different from what had been seen at Alturdyne, it was decided to install a second roller bearing to replace the first and to repeat the test. The engine vibration characteristics were much closer to the original vibration signature with spikes to 0.9 mil on the horizontal probe at no load. At one point during the test, 1.3 mils at the 1F mode was noted when the tailpipe clamp loosened. Once again, the tailpipe was removed with no significant change in the vibration signature. The data from this test is presented in Sections 4c and 4d of Appendix C.

TEST ABOARD LACV-30-1

The engine was transferred to Alturdyne for reinstallation in the module and shipment to Fort Story, Virginia. The module was installed aboard LACV-30-1 with Alturdyne and Bell supervision. Module alignment was checked by relocating the package on the base dowels from the previous test and was found to be acceptable.

All tests were run on November 11, 1976. The first test of the series was a functional check with the bellows panel on and the fan shaft disconnected. Results were essentially as witnessed at Alturdyne, i.e., the 1F amplitude was about 0.35 mil. The vibration signatures are presented in Appendix C, Section 5a. The bellows panel was then removed with the results shown in Section 5b. The 1F mode immediately became the dominant characteristic, with amplitudes of 3.5 mils on the horizontal probe. The fan shaft was installed and the condition worsened with the results shown in Appendix C, Section 5c. Horizontal rotor amplitudes of 4.9 mils were recorded. The bellows panel was installed and the 1F mode once again dropped to or below the amplitude of the first configuration (with bellows on and fan shaft disconnected), as shown in Appendix C, Section 5d.

A test was then run to determine the effect of inlet supercharge on the bearing temperature, possibly as a result of a change in the air split across the labyrinth seal. The engine was run until the bearing temperature stabilized with the lower compartment doors open to bypass the fan air, then with the lower compartment doors closed at about 10 inches supercharge. No change in bearing temperature was discernible.

A load cell was installed in place of the aft mount at this point and a test run was made over land by nosing the craft into a sand bank, then exercising the main engines through their power/speed modes. The load indicator showed approximately a 200- to 225-pound force on the mount. This force was generated over a period of time after the engine/fan had reached operating temperature and was assumed to be thermal growth of the air inlet as restrained by the trunnions/bellows. The force is largely accounted for by a 120-pound engine weight at the mount and by a 50-pound bellows reaction.

The overland flight also yielded a very low order vibration roughly corresponding to propeller blade passage frequency. This appeared on the proximity probes under only a few flight conditions and was not of significant magnitude. The vibration spectrum was normal and stable in all other respects.

The final test aboard the craft was a run over water while exercising the craft through its full flight profile. Sea conditions of 4-foot swells with 25-knot gusting wind provided a realistic test of the level of severity normally encountered during operations. Failure of the generator set placed on board to provide instrumentation power forced abandonment of the test before completion of all phases of operation, but it was felt that the data gathered were adequate. Once again, the craft modes of operation had little or no effect on the vibration signature of the engine.

Final tests under this program involved Solar examination of vibration signatures for a 62T-32 engine in an EMU-30/E Generator Set. This is a Solar unit built under Air Force contract. One of the original reliability test generator sets being prepared for shipment to the Air Force, and the engine in it (S/N 700097) had provision for proximity probes. As a part of its final acceptance, a vibration signature was obtained with the results shown in Appendix C, Sections 6a and 6b. The engine run with exhaust bellows in place (a normal installation in the EMU-30/E resulted in peak excursion 1F vibrations of 1.0 mil with no load and 1.3 mils with load. Significantly, when the exhaust bellows was removed entirely, the peak excursion 1F vibration remained at 1.3 mils. The 1E vibration was steady at 0.3 to 0.35 mil peak excursion throughout the test.

SYSTEM MODIFICATIONS

As a result of this investigation, a number of modifications have been made to improve the APU. These modifications, and the reasons for making them, are listed in Table 4. The current APU arrangement, with the modificiations incorporated, is shown in Figure 5.

IV. CONCLUSIONS

It is concluded that the original APU module arrangement reinforced or excited engine rotor shaft 1F vibrations to potentially destructive amplitudes, and that the vibration was the probable cause of most or all of the LACV-30 APU failures.

Evidence that the levels of excursion measured are destructive to the roller bearing is ample. The rise in bearing race temperature invariably accompanying the vibration is an indication that the bearing is absorbing more energy, either from skidding or from induced misalignment, even though the temperature levels are not destructive of themselves. The presence of 5-mil peak-to-peak excursions at the bearing support snout results in peak loads on the bearing on the order of 200 pounds, at the support spring rate of 80,000 pounds per inch. As may be seen from the bearing life chart of Figure 6, loads of this magnitude combined with misalignment result in bearing life measured in hours rather than thousands of hours.

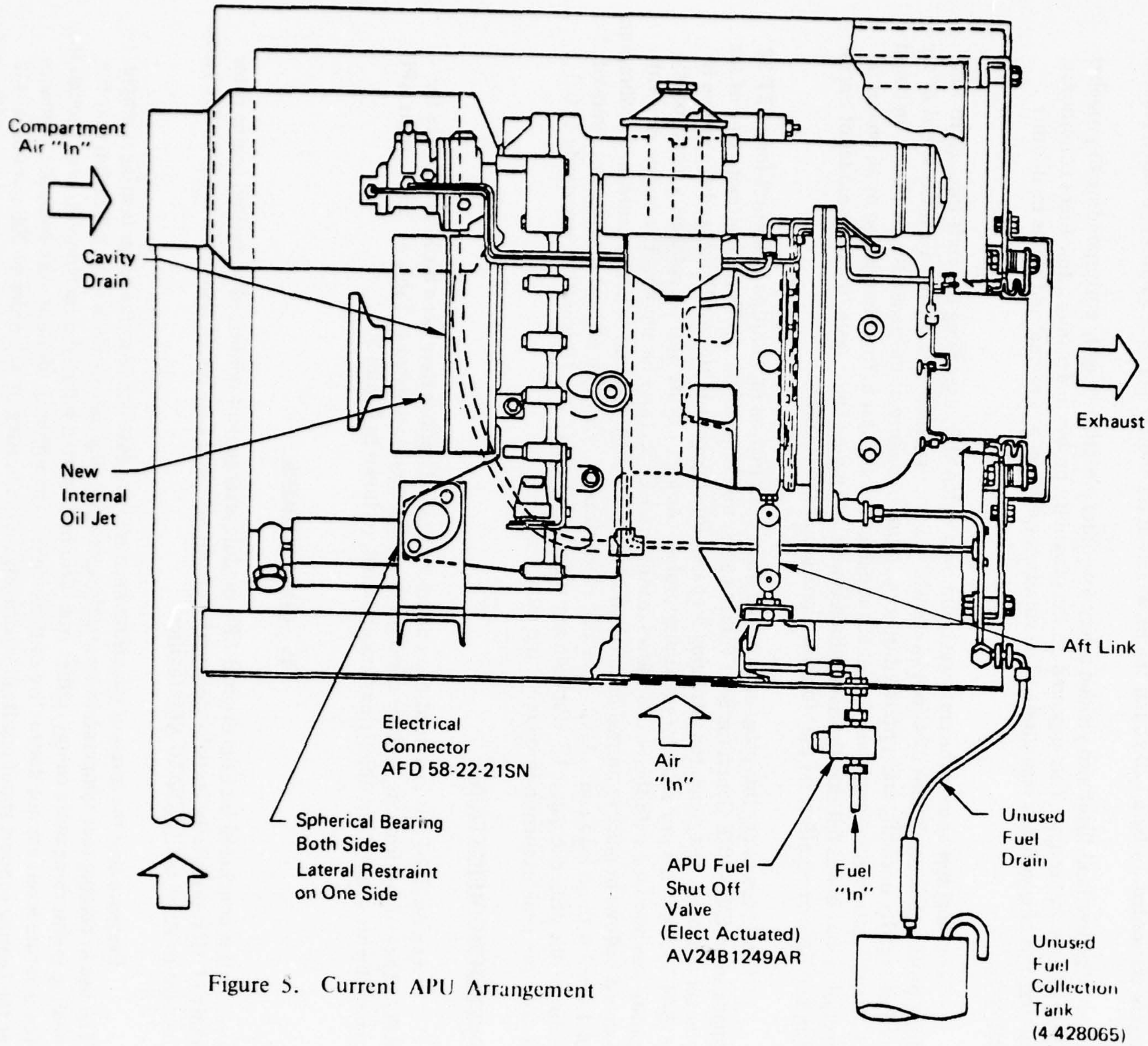


Figure 5. Current APU Arrangement

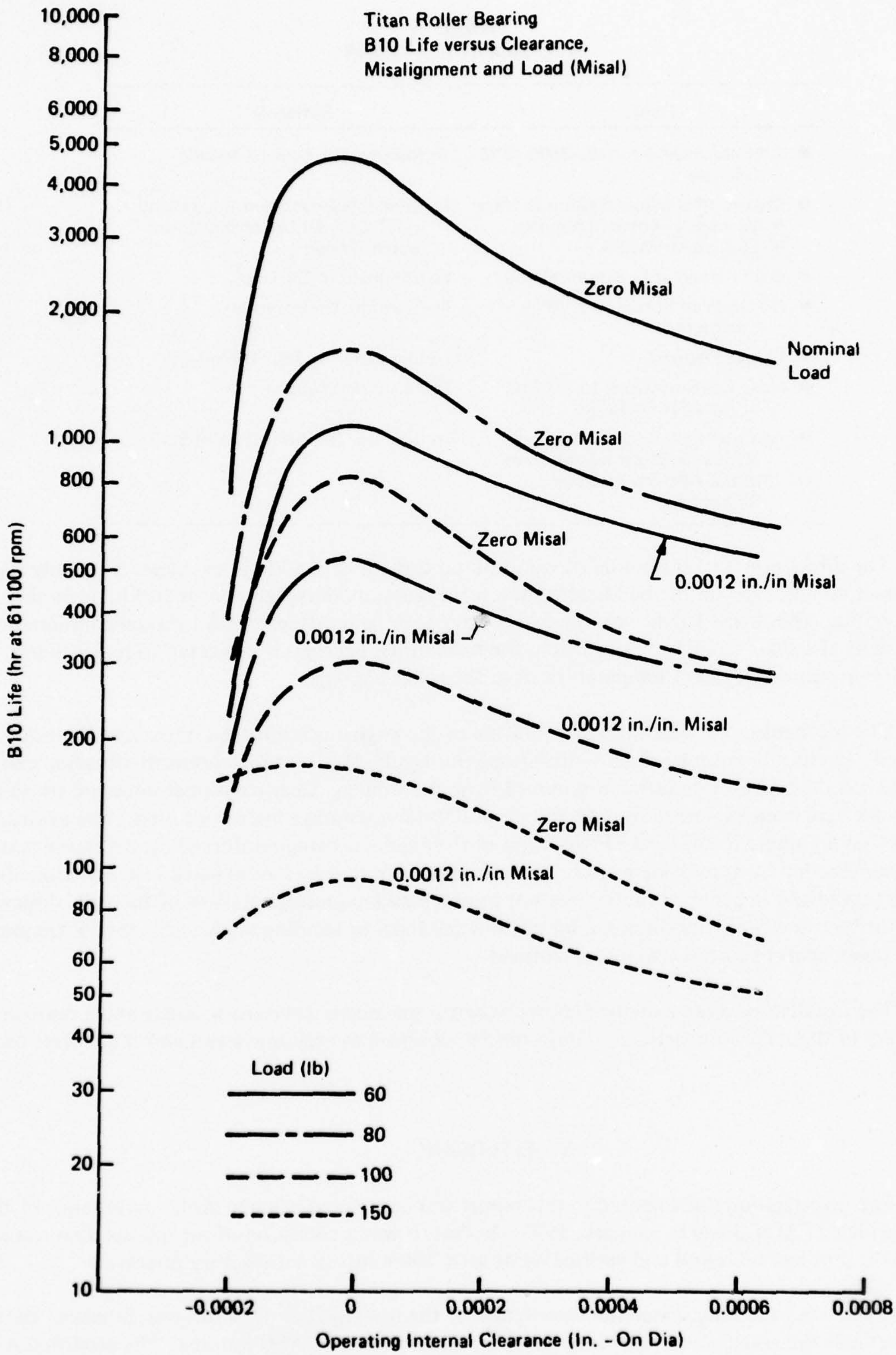


Figure 6. Bearing Life Chart

TABLE 4
APU MODIFICATIONS

Item	Rationale
• Additional Oil Jet in the 3800 RPM Gearbox	To Improve Oil Flow to Bearing
• Change APU Mount System to Have: • Bearings at Forward Mounts • Link at Aft Mount	To Eliminate Redundant Load Paths and Continued Use of the Mount System Tested
• Cavity Drain at Generator Mount	To Eliminate an Oil Trap
• Oil Drain on Port Side of APU Enclosure	To Facilitate Oil Drainage
• Exhaust Bellows	To Eliminate the 250 Hz Mode
• Move Collector Drain to Aft End of the APU Enclosure	To Facilitate Shipment
• Add Instruction to Maintenance Manual to Effect a Cold Crank of the APU after 30 Day Shutdown.	To Circulate Oil Prior to a Hot Start

The direct effect of this mode of vibration on thrust bearing life is less clear. Certainly higher radial loads are imposed on the ball bearing as a force reaction. Misalignment is also induced due to shaft bending. The thrust balance on the ball bearing may be interfered with by axial components produced by the shaft bending. In addition, the ball (thrust bearing) is subjected to higher temperatures due to the increased lubricant temperature from the roller bearing.

The mechanism by which the 1F vibration of the engine is reinforced or excited has not been identified. Excitation from the LACV-30 is ruled out by the fact that high levels of vibration can be sustained with the APU compartment removed from the vehicle. Gear rotational rates and tooth mesh frequencies have been examined, but no source of 250-Hz excitation has been found. The evidence suggests that an inherent low level 1F vibration of the engine is being reinforced by structural coupling. rather than excited by an outside source. It has been shown that lack of exhaust restraint alone (on the Solar test stand and in generator sets) does not produce such coupling. Review of the APU design by Bell, Alturdyne and Solar has disclosed no obvious torsional or bending modes near the 1F frequency, but a detailed analysis or test was not performed.

The installation of an exhaust bellows between the engine combustor flange and a reinforced back panel of the APU compartment damps the 1F vibration to very low levels and thus solves the problem.

V. EPILOGUE

The investigation documented in this report was completed prior to Army acceptance of the second vehicle (LACV-30-1) in January, 1977. In fact, it was a condition of acceptance that a solution to the APU problem be found and verified by at least 100 hours of satisfactory operation.

Operating experience since the completion of the investigation is of interest, however, because it substantiates the conclusions regarding the cause and solution to APU failures. The modified APU (engine S/N 750228) has continued to perform satisfactorily on LACV-30-1. As of June 1, 1977, it

has logged 387 hours of operation. The unmodified APU (S/N 750192) on LACV-30-2, on the other hand, experienced a thrust bearing failure on March 21, 1977, after 310 hours of operation.

The LACV-30-2 APU, with replacement engine S/N 750246, was fully modified with exhaust bellows, stiffened panel, and lubrication system and engine mount changes. On May 10, after 73 hours of operation, an unusual noise was heard on APU shutdown and excessive radial play in the rotor was reported. Later measurements showed the radial play to be about 0.006 inch, the same as a new unit. The engine was started and found to run normally; however, higher than normal levels of 250-Hz vibration were measured on an accelerometer mounted on the combustor flange. This vibration could be damped by holding a piece of wood between the starter and air inlet housing. As a precautionary measure, the engine was removed and replaced with S/N 750192 (reworked). Also, the exhaust bellows was replaced by a new design having about twice the spring rate as the original. As of June 1, this unit had accumulated 10 hours of operation.

It is suspected that the bellows on S/N 750246 lost compression as a result of a combustor clamp failure some 7 hours prior to the reported problem and precautionary changeout. The clamp failure allowed the combustor to move toward the bellows by 3/8 of an inch, and may have produced a permanent set.

Both vehicles have been equipped for continuous monitoring from the cabin of the 250-Hz mode of vibration. LACV-30-1 displays roller bearing temperature, which has been shown to exhibit a definite rise when excessive vibration is present. LACV-30-2 displays combustor flange acceleration, filtered to pass 230 to 270 Hz.

APPENDIX A

WORK STATEMENT FOR RETURN TO SERVICE – ALTURDYNE APU P/N [illegible]

9/ 9/76

REV. A 9/14/76

1.0 Gearbox in semi-stripped-down condition at completion of investigation.

2.0 Gearbox to be completely disassembled. Bearings, seals, O-rings to be removed and discarded together with other consumables.

3.0 All components, casings, etc. to be cleaned with special attention to cored or drilled oil ways and lines.

4.0 A means of providing a positive supply of oil shall be included for the bearing at the engine end of the output shaft.

5.0 All components and casings shall be inspected for latent flaws prior to reassembly.

6.0 The gearboxes shall be reassembled to normal shop practices.

6.1 A magnetic plug shall be inserted in the gearbox sump.

6.2 Install a new gas turbine engine P/N 116901. Verify proper injector O-ring installation. Verify build history documentation.

7.0 A generator drive pad drain shall be added and plumbed in such a way that all engine drains terminate at one connection on the mount frame from which the combined leakage may be routed to a drain tank. Provisions will be made to ensure that leakage from one pad will not back up to an unaffected pad. There shall be no rigid connections between the engine and frame.

8.0 A drain line shall be provided tö drain gearbox oil. Such a drain will be adequate for oil drainage at -40°F and will terminate in the mount frame such that the oil may be collected outside the casing. There shall be no rigid connection between frame and engine.

9.0 A longer gasket shall be manufactured to effectively seal the fuel control drive cavity from external contamination. This gasket shall be identified by P/N for spares provisioning.

10.0 The door gaskets on the APU housing shall be repaired or replaced as required.

11.0 Provisions shall be made to prevent external contamination collecting in the plug cavity between the Alturdyne and Solar gearboxes.

The mounting arrangement shall be reviewed to a mutually agreeable design as determined by Solar, Alturdyne and Bell. This arrangement shall be designed and incorporated into the assembly.

12.0 Test Procedures.

12.1 The engine shall be tested at the Alturdyne facility with the following criteria:

a. Startups shall be automatic and controlled to the same limiting criteria as in the vehicle installation.

b. Oil temperatures and pressures into the engine shall be recorded at sufficient intervals to establish any trends.

c. E.G.T. shall be recorded at startup and after stabilization on load changes.

A Bell Aerospace representative shall witness the test.

12.2 Test Plan.

a. The test shall cover 8 hours of engine operation at 100% speed.

b. The test shall be subdivided into half-hour increments. Each half-hour period shall consist of:

1) Engine start to 100% speed.
2) 1 minute stabilization.
3) Apply step load equivalent to 90 HP.
4) After 6-1/2 minutes the load shall be removed as a step function.
5) 1 minute of zero load.
6) Repeat 3 and 4.
7) Repeat 3, 4 and 5.
8) Repeat 3, 4, and 5.
9) Shut down plant.
10) Repeat 1 thru 9, 15 times for a total of 8 hours. At least 8 of the 16 starts shall be accomplished with a residual E.G.T. of between 250 and 300°F.

c. A log shall be maintained during the tests showing all test parameters including: oil pressure, oil temperature, E.G.T. and load. The magnetic plug and filter shall be checked at approximately 4 hours and at the end of the test. A new filter shall be installed prior to shipment. Oil shall be drained at the completion of the test and visually checked for contamination and samples checked by Solar under a S.O.A.P. test or equivalent.

13.0 After completion of testing the complete package shall be shipped by air to:

LACV-30, Capt. Haskins
Lighter Air Cushion Vehicle
Fort Story, Virginia
Attention: Mr. C.S. Watt

Mr. N. Travis of Alturdyne shall be on hand at Fort Story, Virginia to witness and supervise installation and start-up of the APU assembly on LACV-30-1.

APPENDIX B
INVESTIGATION AND ANALYSIS OF LACV-30 AUXILIARY POWER UNIT FAILURES
5 OCTOBER 1976

1.0 INTRODUCTION

As a result of multiple failures of the Auxiliary Power Unit on the LACV-30 craft being tested and evaluated by the U.S. Army it is necessary to conduct an investigation into the cause of such failures and take corrective action as may be indicated. On 29 September 1976, Bell Aerospace Textron met with personnel of the U.S. Army Mobility Equipment Research and Development Command, including the Contracting Officer's Technical Representative, and formulated an approach. It was agreed that Bell, being the prime contractor, would be responsible for organizing and implementing the investigation program and that the APU supplier, Alturdyne, and the turbine manufacturer, Solar, should participate in accordance with appropriate Statements of Work to be negotiated between Bell and each participant.

2.0 APPROACH

2.1 Bell will develop a set of parameters deemed to be pertinent to the investigation and identify appropriate instrumentation and recording equipment for obtaining data. Bell will solicit approval, concurrence and/or comment from Alturdyne and Solar on the parameters and instrumentation plan.

2.2 Instrumentation will be installed on and around the APU on LACV-30-2 at Aberdeen Proving Ground to gather baseline data on that installation. Such data will be examined for any indication as to where failures may originate.

2.3 Bell, with the cooperation of Alturdyne and Solar, will obtain on-the-bench vibration characteristics of a new (replacement) APU. Then, with the cooperation of MERADCOM, Bell will obtain similar data on T62 turbines in service to obtain a sampling of the vibration spectrum inherent in the turbine family and to validate methods of measurement.

2.4 A replacement APU will be installed on LACV-30-1 at Fort Story and after completing 2.2 and 2.3 above the instrumentation package from LACV-30-2 will be installed on that craft and an incremental test program conducted. In lieu of other limits, the maximum values obtained on LACV-30-2 will be the criteria to discontinue testing for in-depth analysis and corrective action.

2.5 Bell will coordinate the overall program but it is planned as a joint effort in that personnel representing each concerned organization shall be on-site to concur on the validity of the test, the effectiveness of the instrumentation, the value of the data, the analysis required and corrective action indicated.

3.0 PROPOSED INSTRUMENTATION

3.1 Parameter List - See Figure B-1.

3.2 Data Acquisition System - see Figure B-2.

No.	Type	Location
1	Tri-Axial Accelerometer	Fwd. Stbd. Mount
2	Tri-Axial Accelerometer	Combuster Mount (Top)
3	Tri-Axial Accelerometer	6000 RPM Reduction Gearbox (Top)
4	Thermocouple	A.C. Gen. Outlet (Air)
5	Thermocouple	Air Temperature at Control Wiring
6	Thermocouple	EGT Harness Temperature (Air)
7	Thermocouple	APU Air Inlet
8	Thermocouple	AMS Air Intake
9	Pressure Transducer	APU Compartment - Upper
10	Pressure Transducer	APU Compartment - Lower
11	Pressure Transducer	Stbd. Power Section Air Inlet
12	Pressure Transducer	AMS Starboard Plenum Between Donaldson & Peerless
13	Strain Gauge	APU Rear Mount
14	Speed Transducer (Existing)	6000 RPM Gearbox
15	Resistance Probe	Temperature out of Oil Cooler
16	Microphone	APU Compartment (upper stbd.)

Note: Strain Gauge (Parameter 13) failed in checkout and was inoperative for test series.

Figure B-1. Parameter List

3.3 Implementation will be accomplished by Bell in accordance with the approach outlined above. Instrumentation and recording equipment will be Bell property, provided on loan to the investigation, insofar as such equipment is available. Additional equipment may be provided by other participants as may be subsequently determined. A van will be outfitted with appropriate Bell-owned data processing equipment.

4.0 WORK STATEMENT - ALTURDYNE

4.1 Provide Bell Aerospace Textron with concurrence with, or addition to, the parameter list of Item 3.1 above and similarly with the instrumentation list of Item 3.2 above. Provide recommendations for test plans/procedures.

4.2 Assist Bell personnel in examination and analysis of baseline data obtained from LACV-30-2.

4.3 Review Bell drawings which pertain to installation of the APU and critique with regard to possible causes of failure. Recommend design changes which could reduce or eliminate likelihood of failure.

4.4 Upon receipt of failed APU from Fort Story, remove turbine/gearbox assembly from Alturdyne gearbox and return to Solar. Disassemble Alturdyne gearbox and examine all parts for any evidence of improper wear or function. This gearbox, having been common to five failed APU's, shall be critically inspected to assure that no out-of-tolerance condition exists.

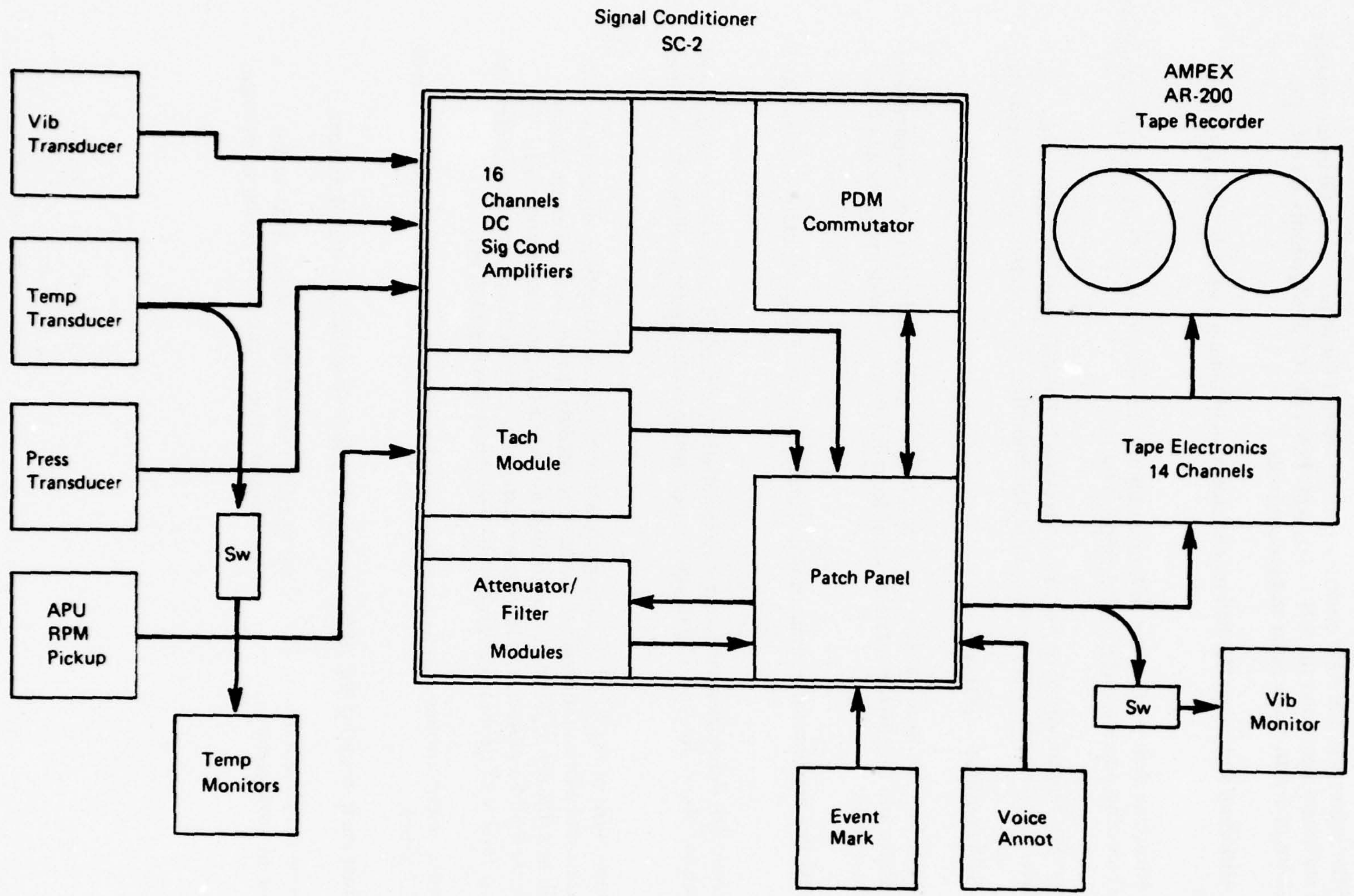


Figure B-2. APU Data Acquisition System

4.5 After inspection, the APU assembly shall be readied for return to service in accordance with the work statement generated for S/N 114-1, APU P/N 128-10590 (Appendix A) with the following additions and with a new Solar turbine assembly.

4.5.1 Alturdyne shall assist the Bell representative in obtaining basic vibration data per Item 2.3 above.

4.5.2 Alturdyne shall prepare the APU assembly for shipment to Fort Story and include within the container a recording accelerometer, to be supplied by Bell.

4.6 Provide a representative to Fort Story to assist in installation of the APU, in the evaluation of data, in subsequent analysis and in the determination of corrective action or redesign.

5.0 WORK STATEMENT – SOLAR

5.1 Provide Bell Aerospace Textron with concurrence with, or additions to, the parameter list of Item 3.1 above and the instrumentation list of Item 3.2 above. Provide recommendations for test plans/procedures.

5.2 Assist Bell personnel in examination and analysis of baseline data obtained from LACV-30-2.

5.3 Review Bell drawings which pertain to installation of the APU and critique with regard to possible causes of failure. Recommend design changes which could reduce or eliminate likelihood of failure.

5.4 Upon return of the failed turbine/gearbox assembly from Alturdyne, disassemble both turbine and gearbox and ascertain the failure mode. The gearbox, having been common to five failed APU's shall be critically inspected to assure that no out-of-tolerance condition exists. The turbine components shall be subjected to laboratory inspection/analysis as appropriate to determine failure modes, e.g. fatigue of the bearing carrier tube, fracture of bearing race, etc.

5.5 A replacement turbine shall be assembled to the gearbox and a baseline vibration survey made per Item 2.3 above.

5.6 Participate in readying the APU assembly for return to service per Item 4.5 above.

5.7 Provide a representative to Fort Story to assist in installation of the APU, in the evaluation of data, in subsequent analysis and in the determination of corrective action or redesign.

APPENDIX C

VIBRATION SIGNATURES

APPENDIX C

SECTION 1

ENGINE S/N 750192 AT ABERDEEN
ABOARD LACV-30-2

1a - Inlet Vertical Accelerometer, APU with Fan Driven

1b - Inlet Vertical Accelerometer, APU with Fan Driven, Peak Hold Mode

1c - Inlet Vertical Accelerometer, APU with Fan Driven, Main Engines at Idle

1d - Inlet Vertical Accelerometer, APU with Fan Driven, Craft Underway

1e - Inlet Vertical Accelerometer, APU with No Fanshaft

Inlet verticals were selected because they yielded the highest g-level.

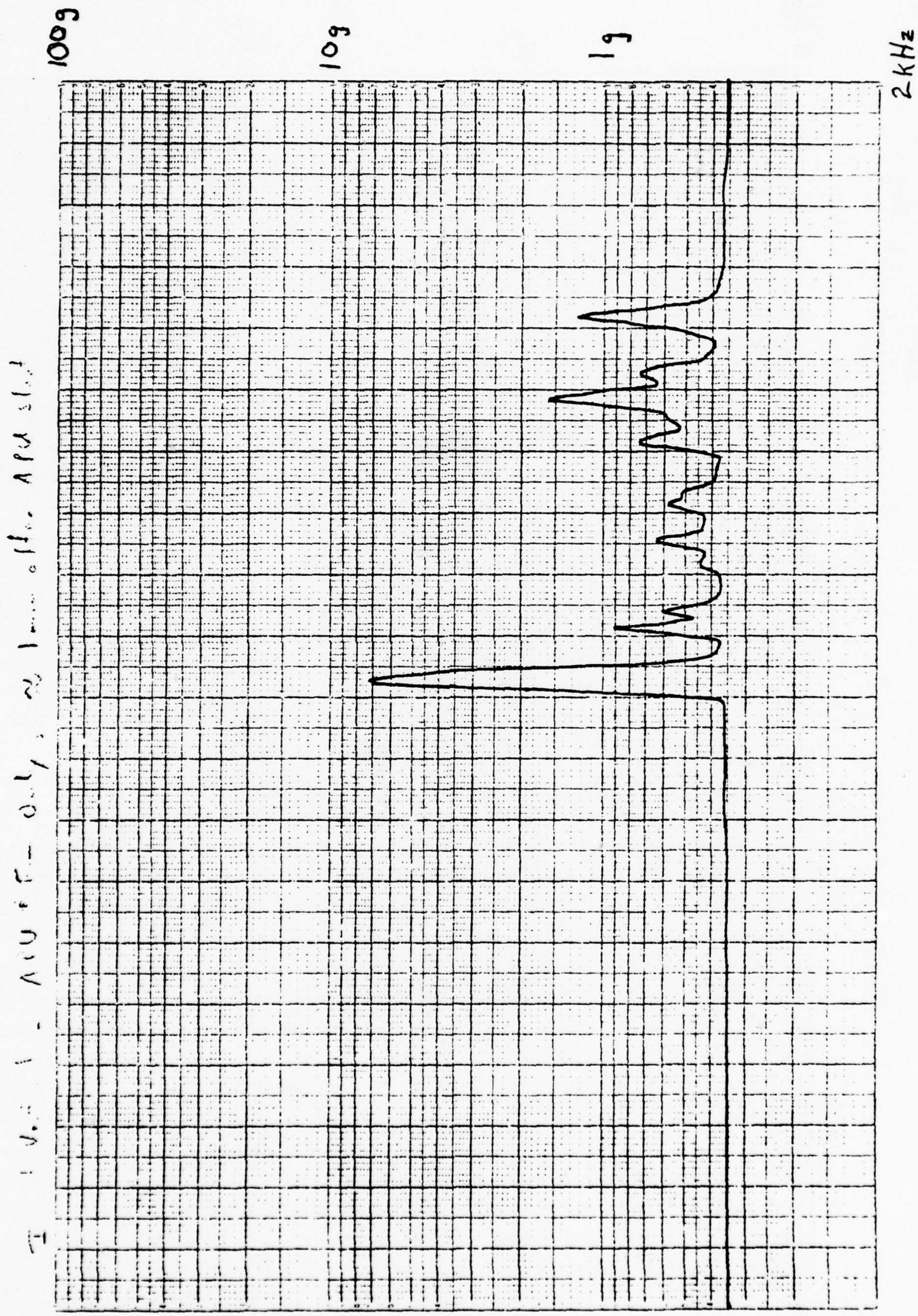


Figure 1a

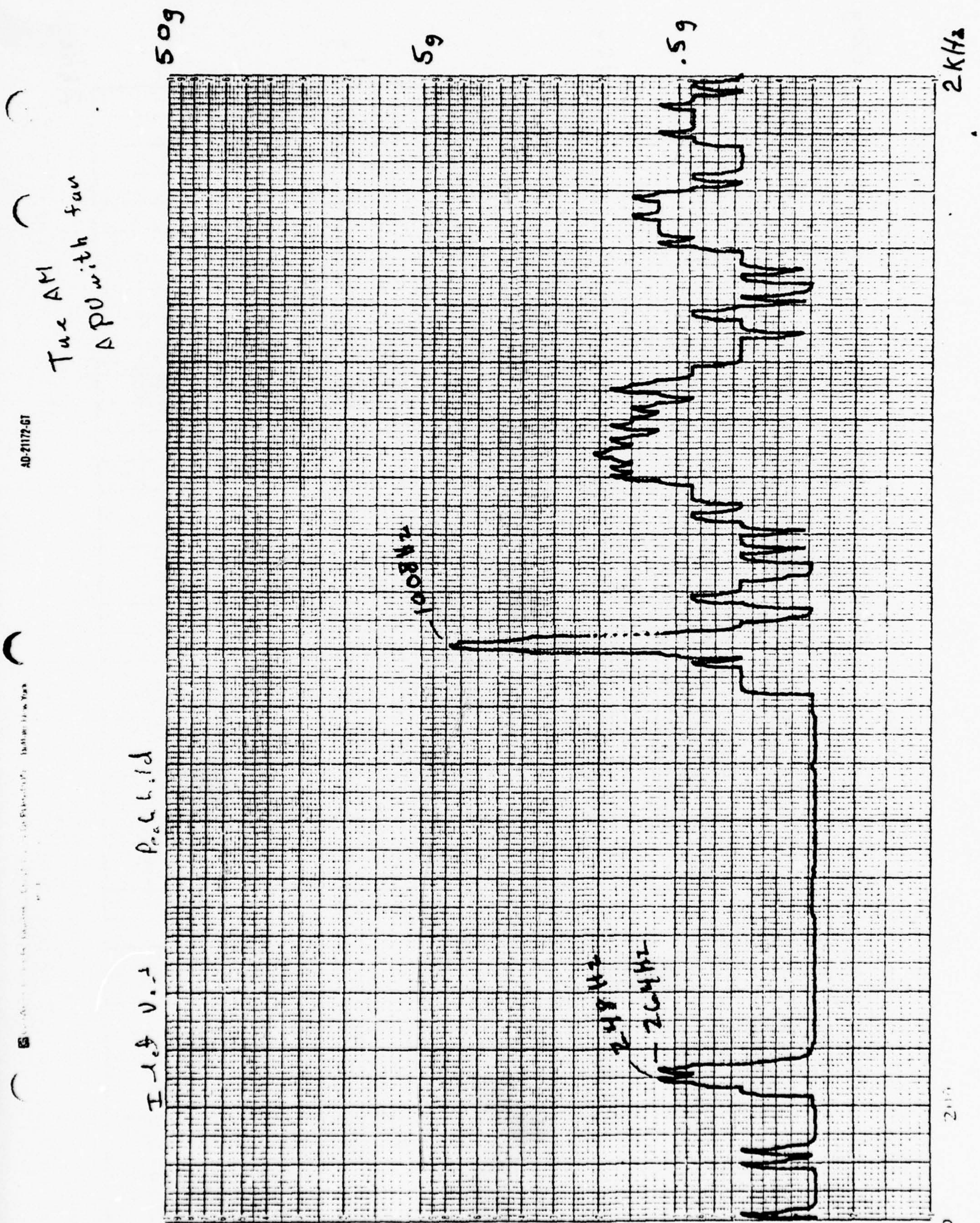

AD-21172-GT
Tue AM
APU with fan
50g
5g
.5g
2KHz
1008Hz
248Hz
264Hz
0

Figure 1b

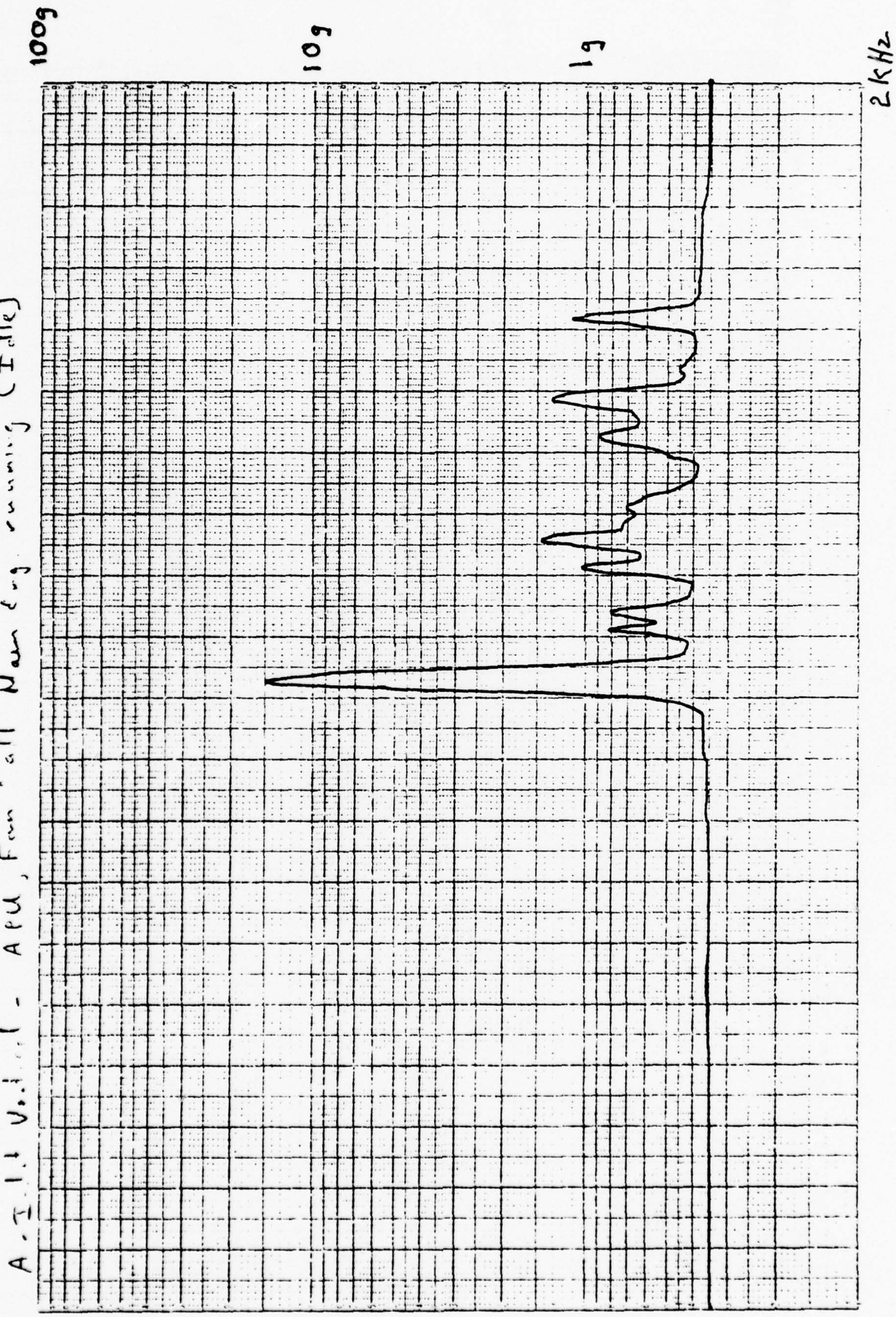


Figure 1c

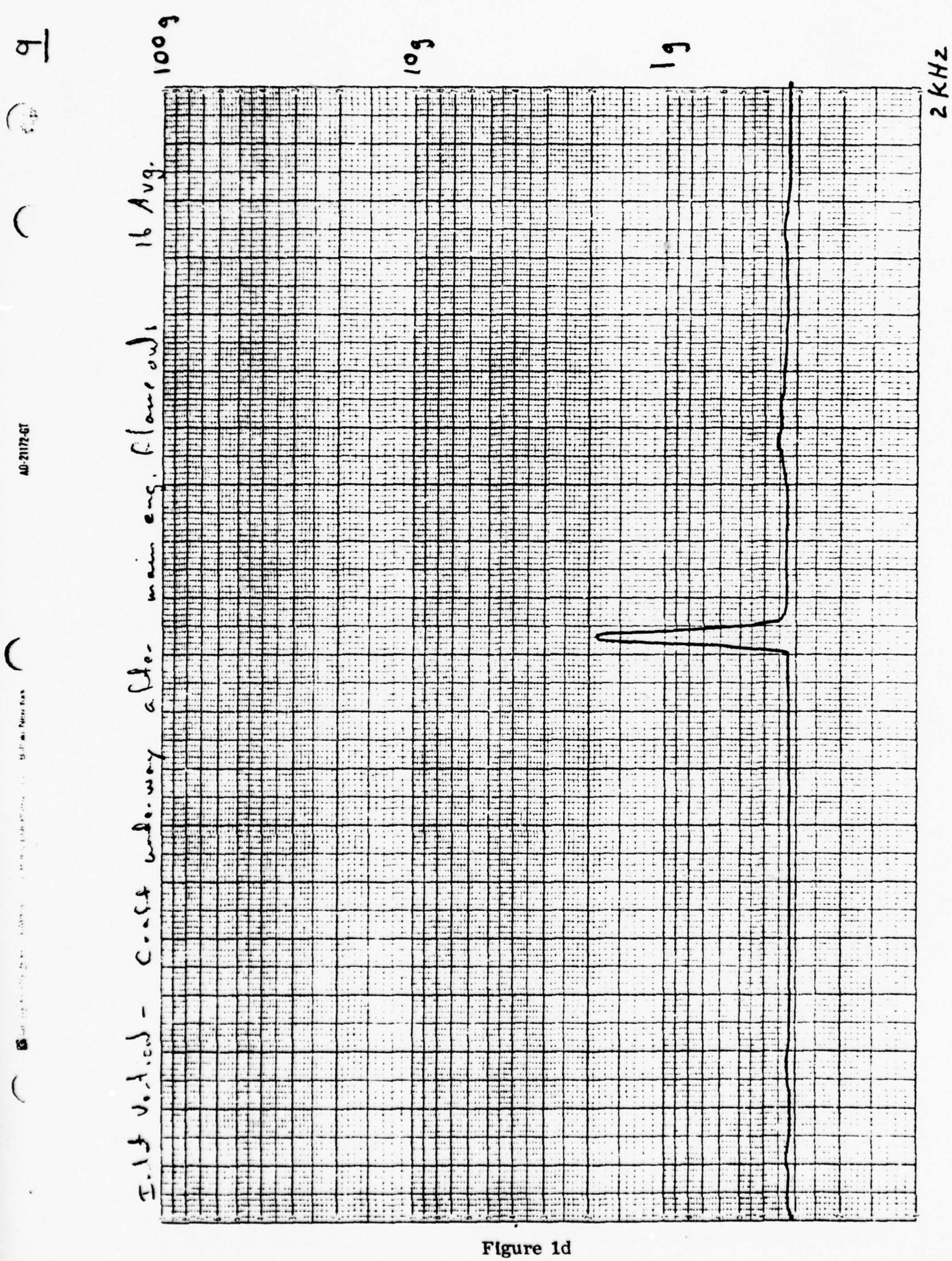


Figure 1d

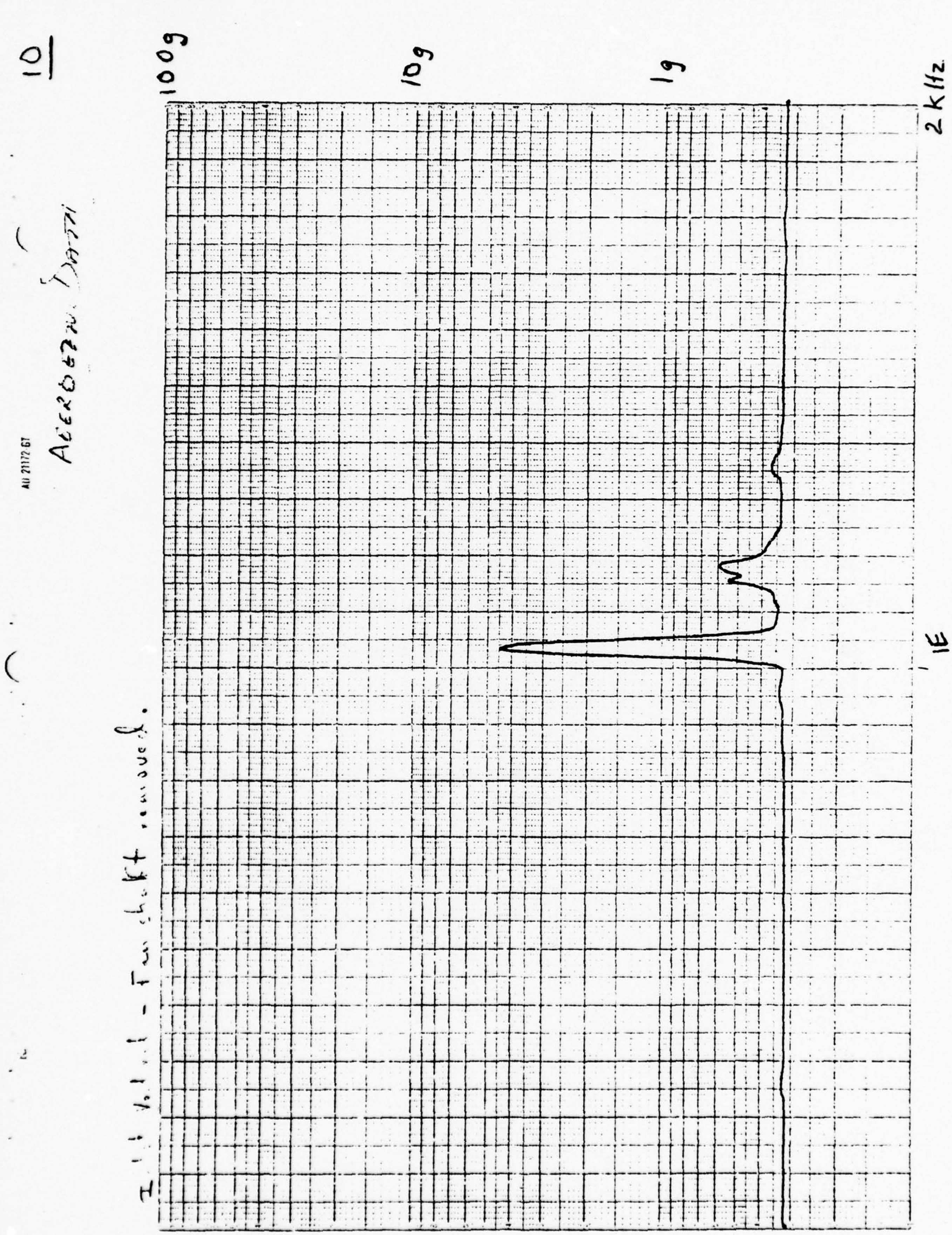


Figure 1e

APPENDIX C

SECTION 2

ENGINE S/N 750228 AT SOLAR
ON TEST STAND

2a - Inlet Vertical Accelerometer at 0 kW

2b - Vertical Proximitor, Peak (Sh. 1) and Minimum (Sh. 2) 0 kW

2c - Horizontal Proximitor, Peak (Sh. 1) and Minimum (Sh. 2) 0 kW

2d - Vertical Proximitor, Peak (Sh. 1) and Minimum (Sh. 2), 72 kW

2e - Horizontal Proximitor, Peak (Sh. 1) and Minimum (Sh. 2) 72 kW

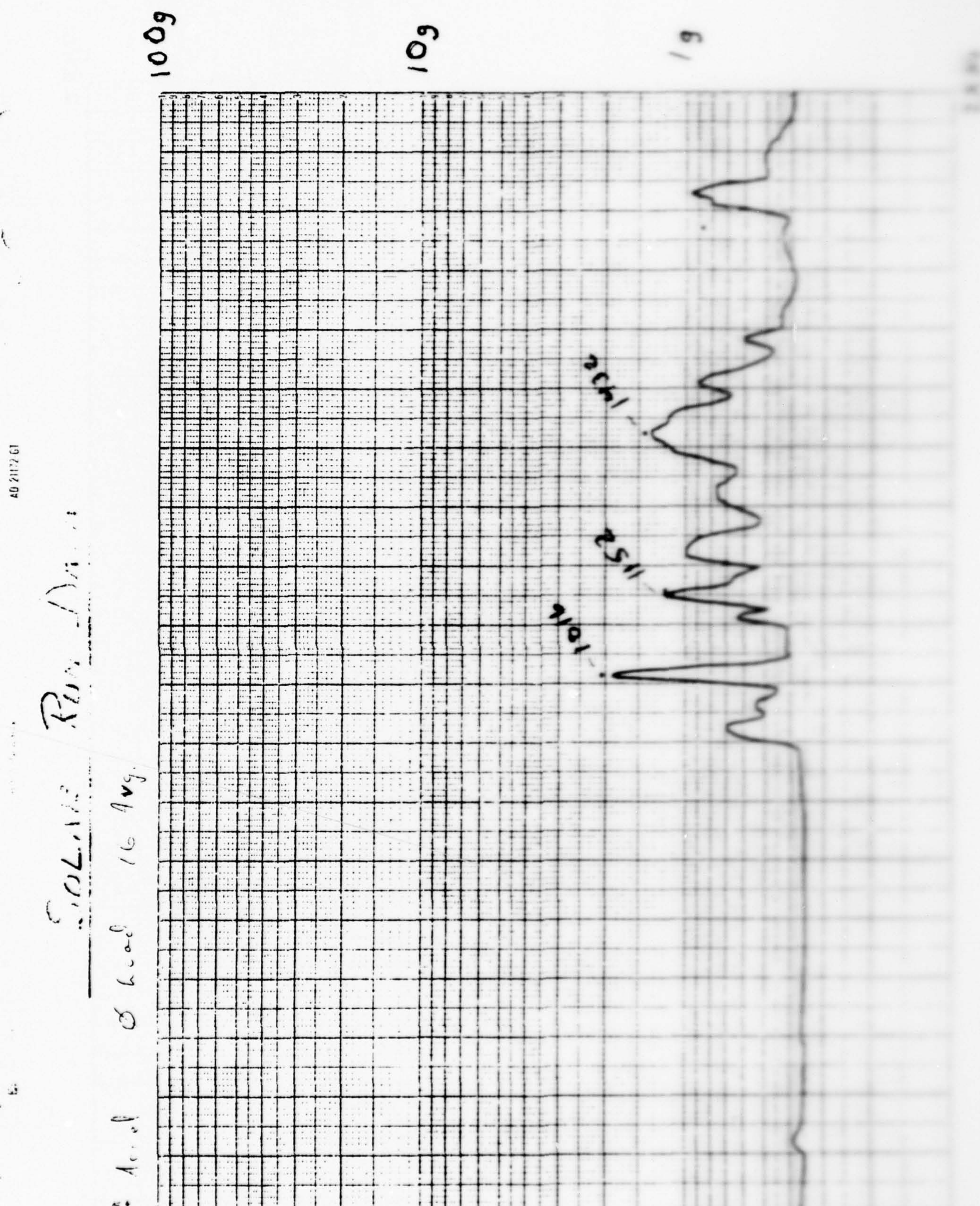


Figure 2a

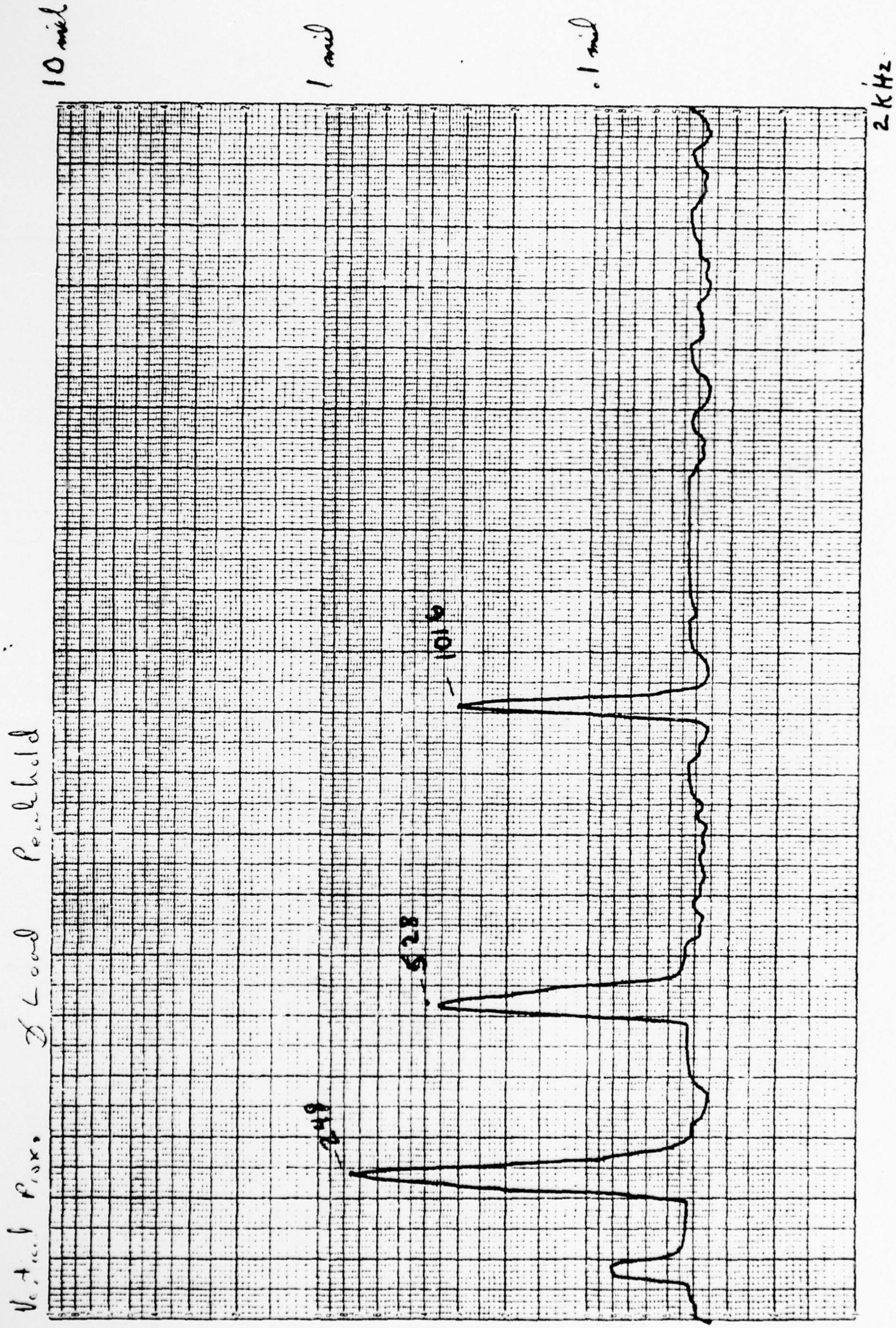


Figure 2b, Sheet 1

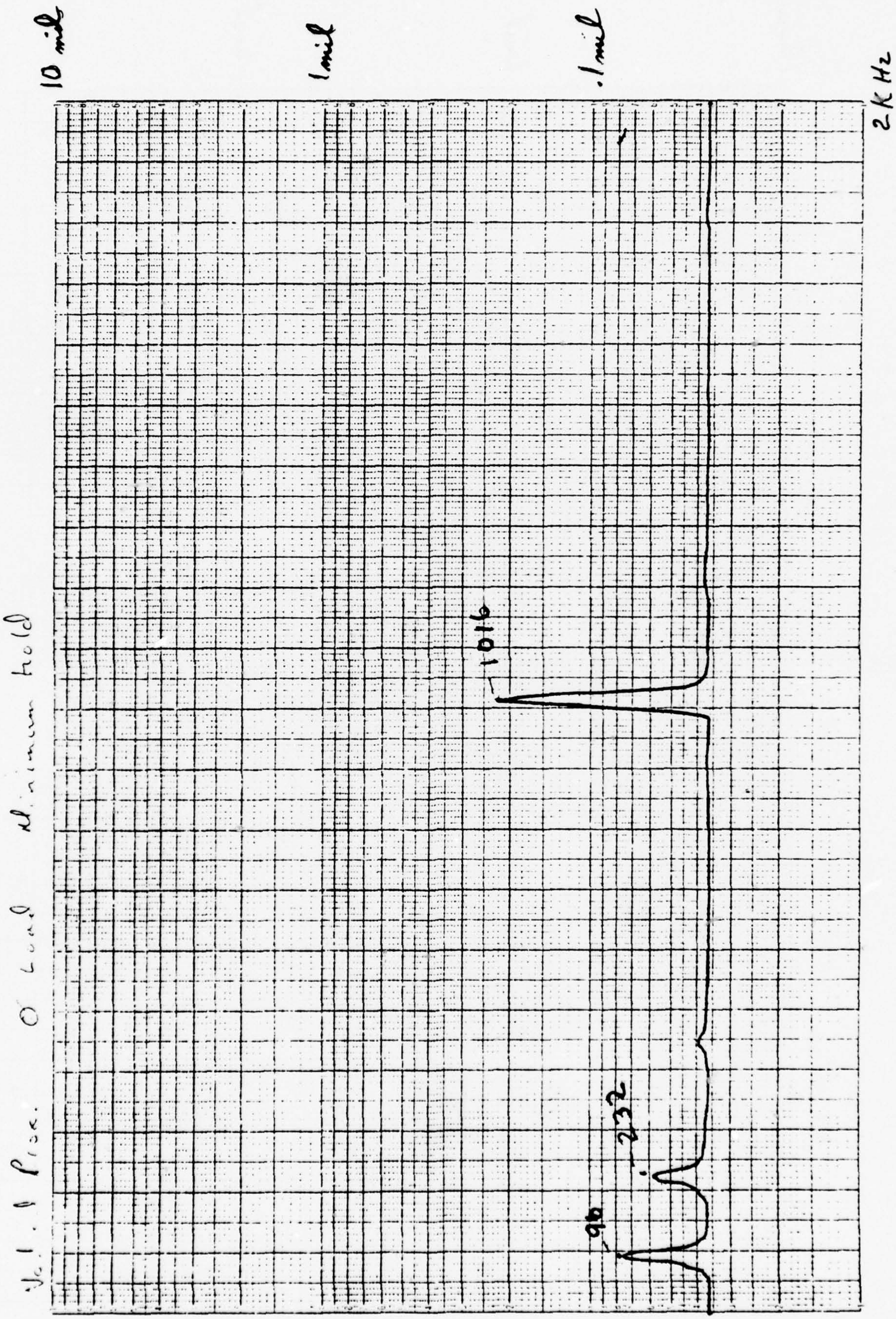


Figure 2b, Sheet 2

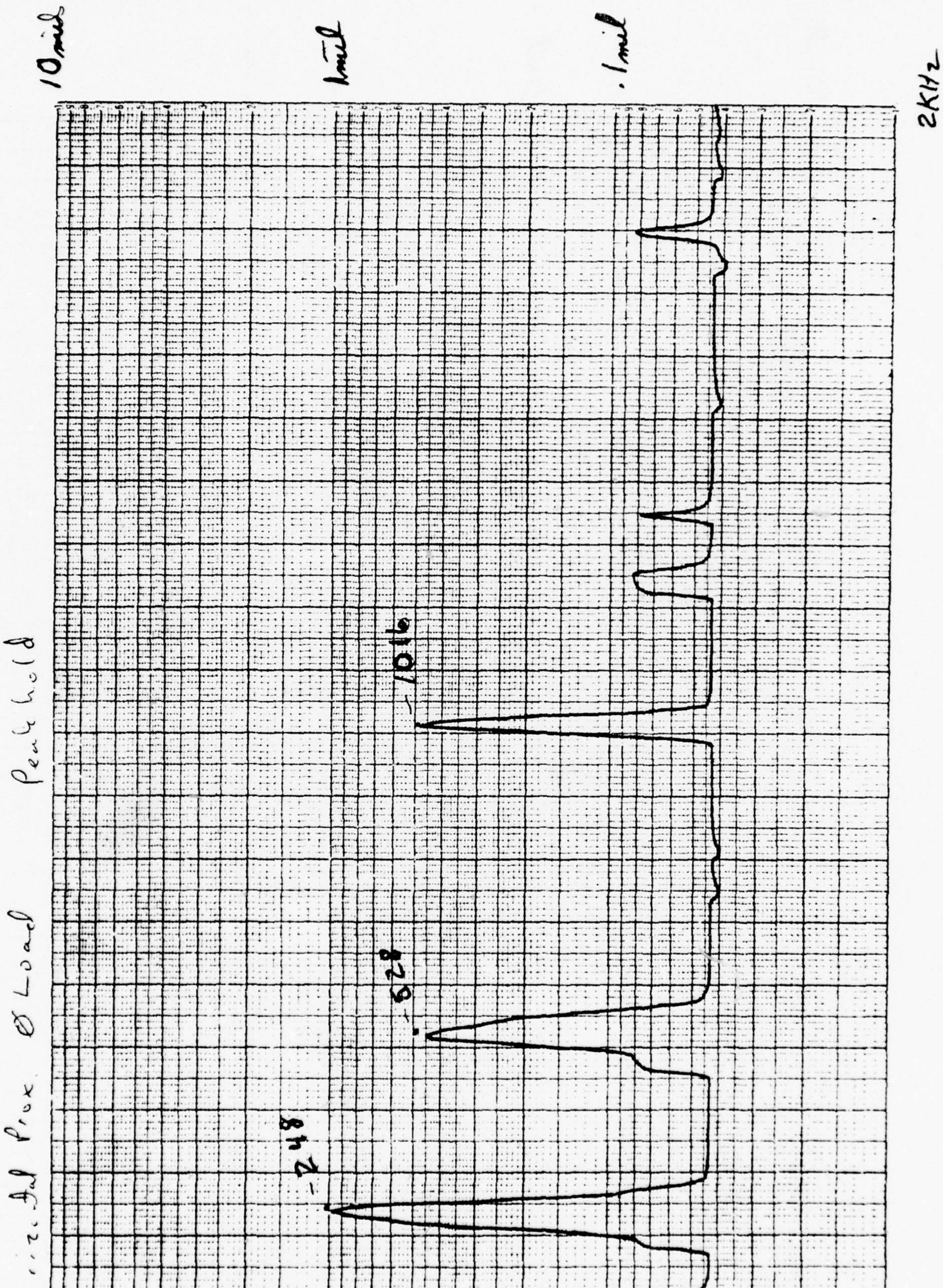
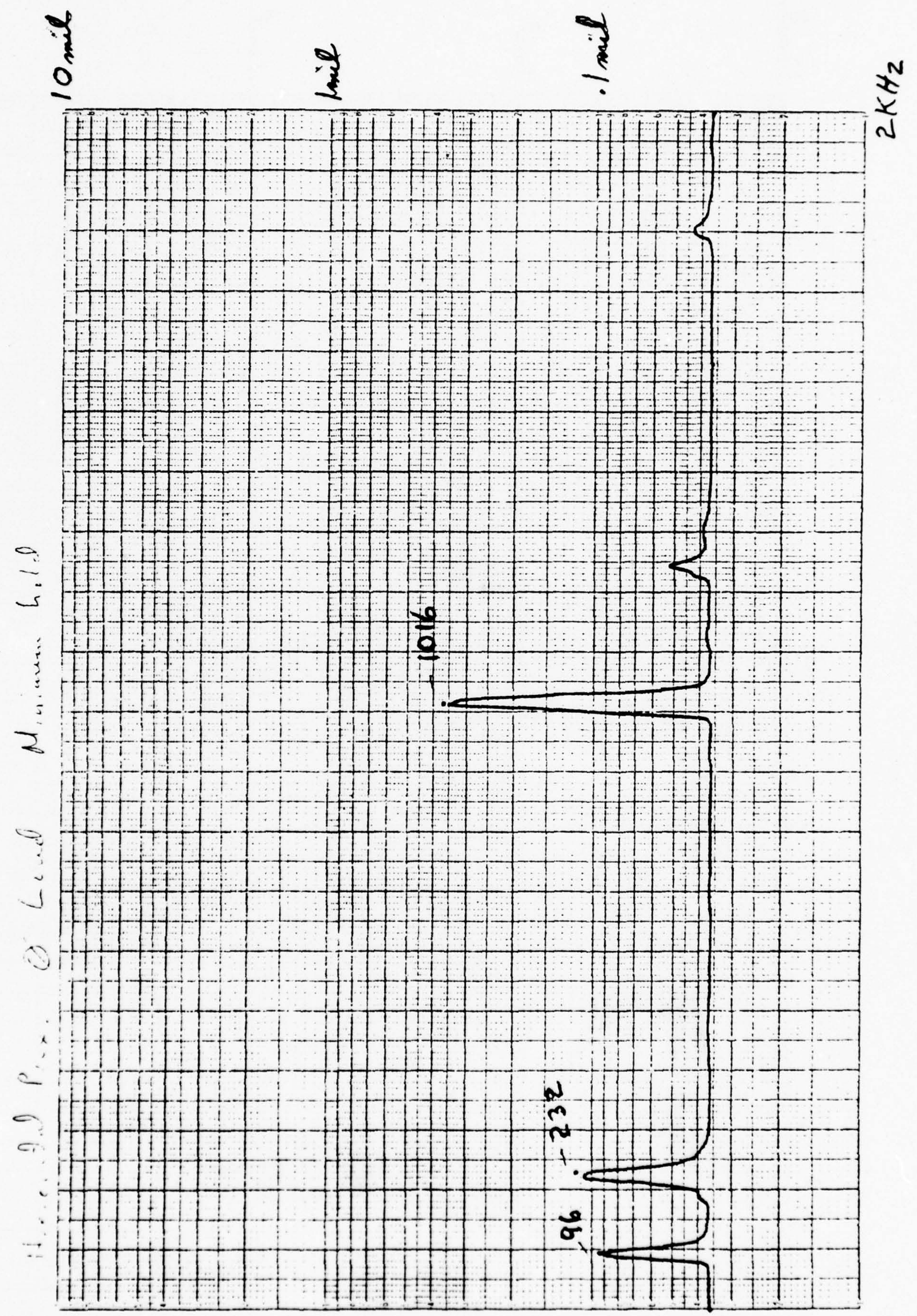


Figure 2c, Sheet 1



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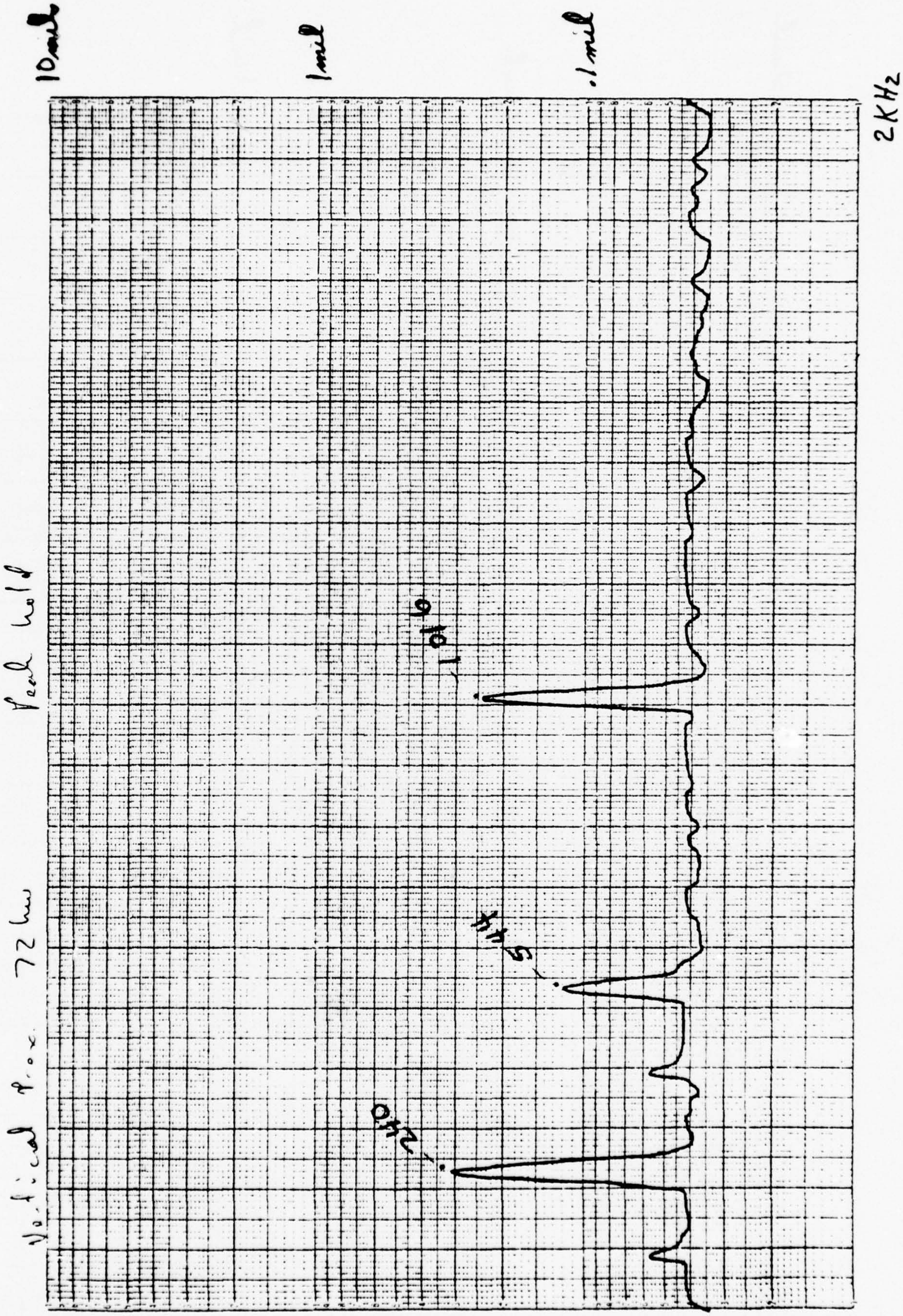


Figure 2d, Sheet 1

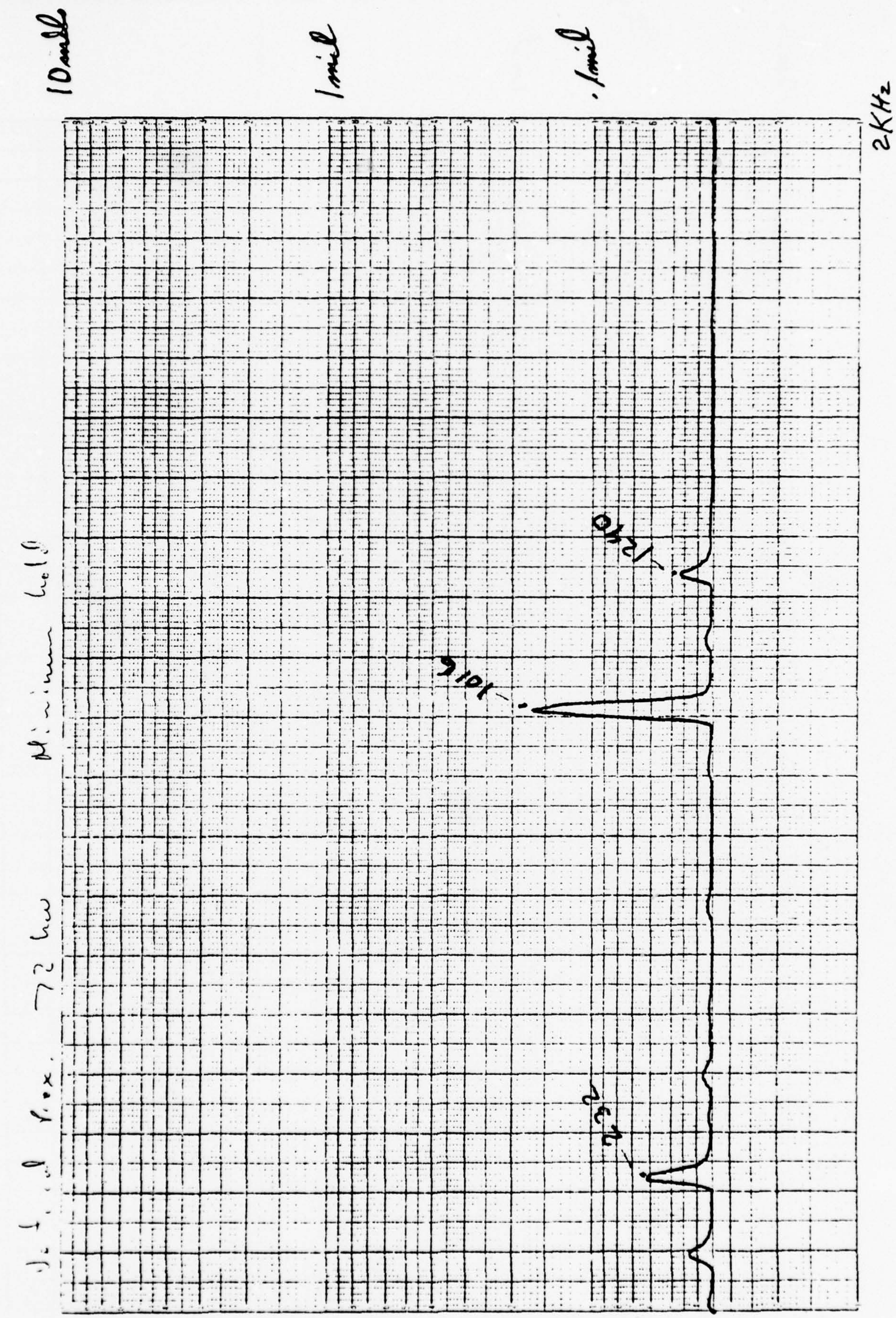


Figure 2d, Sheet 2

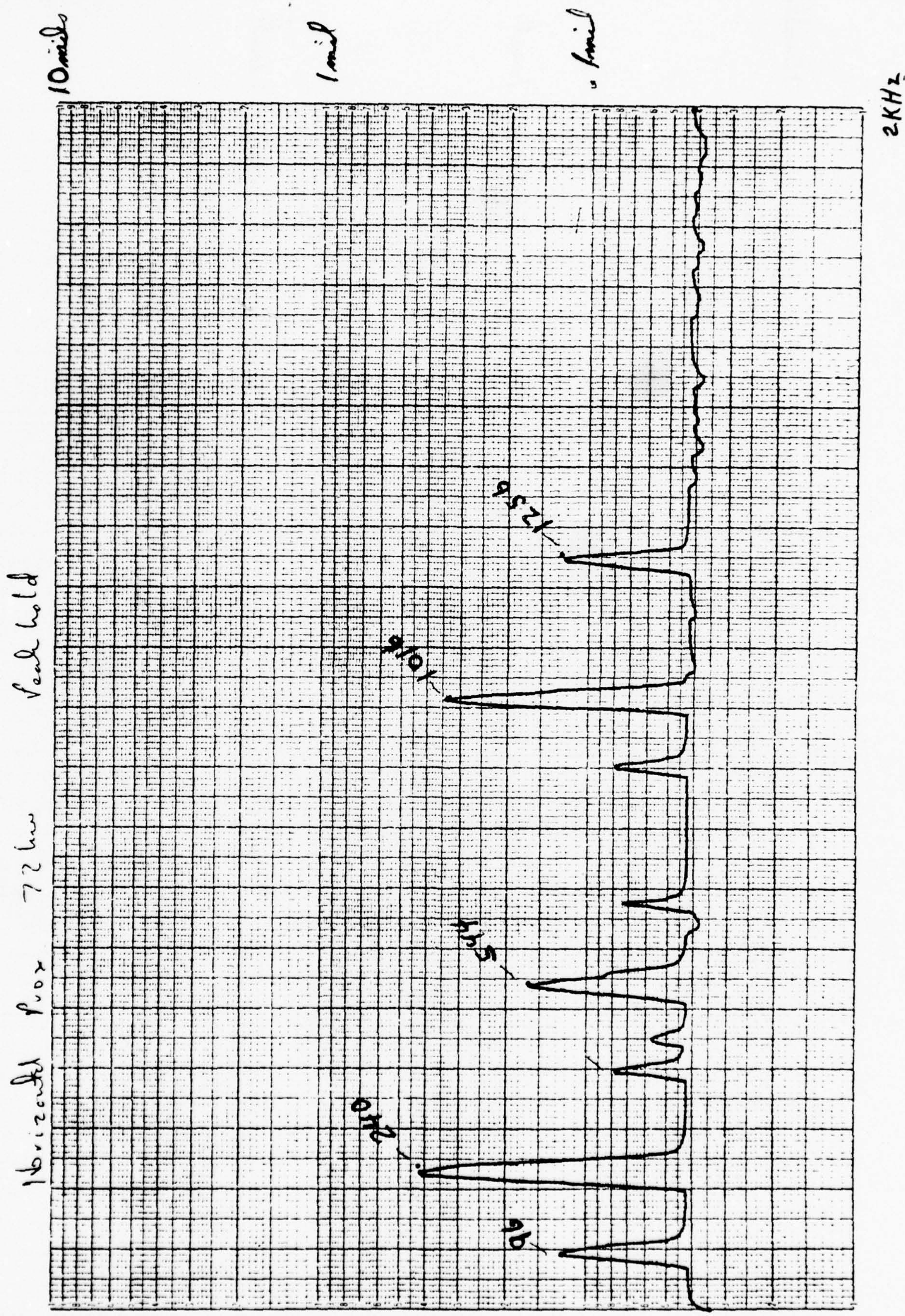


Figure 2e, Sheet 1

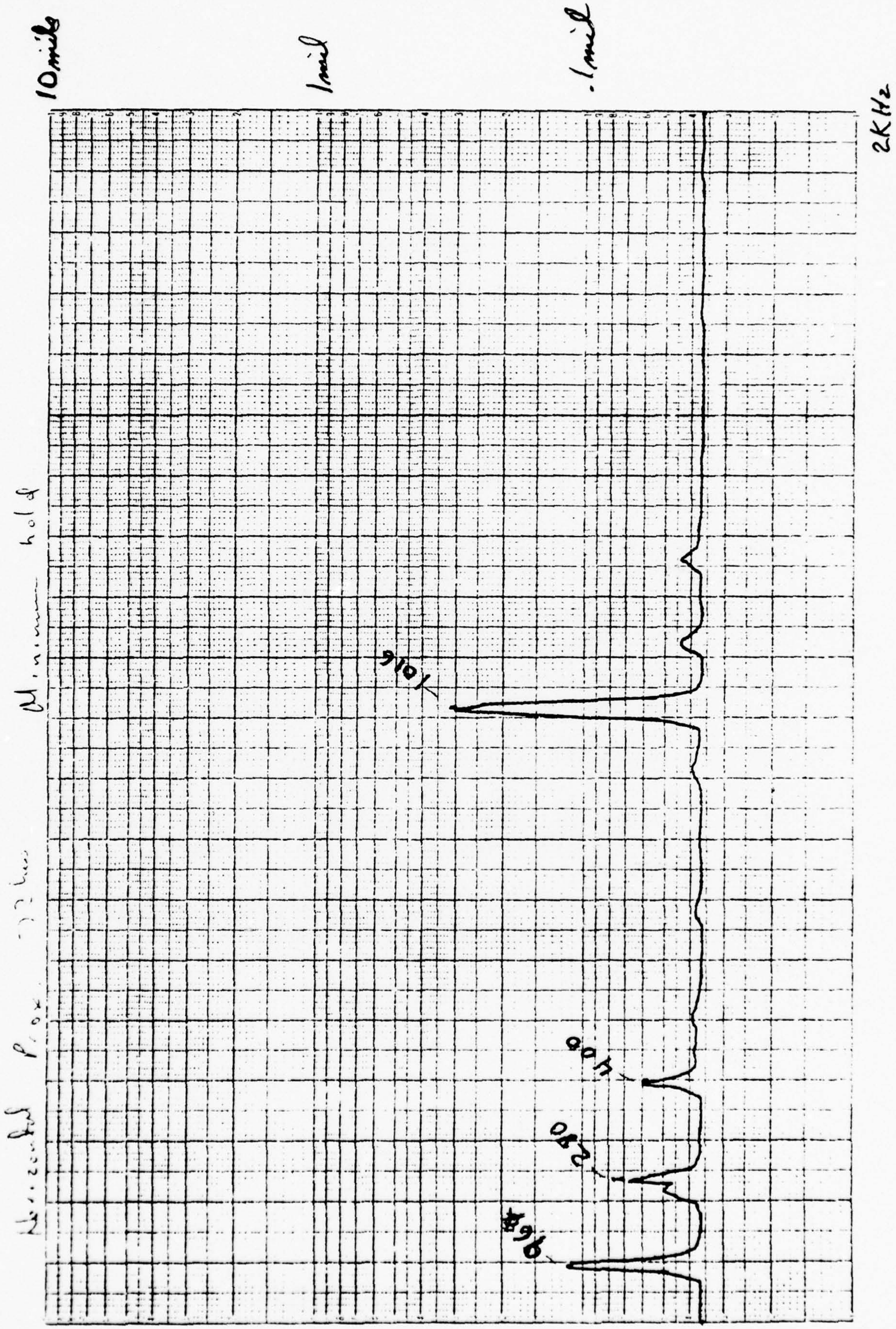


Figure 2e, Sheet 2

APPENDIX C

SECTION 3

ENGINE S/N 750228 AT ALTURDYNE
IN BELL MODULE

3a - Vertical Proximity Probes, Peak (Sh. 1) Minimum (Sh. 2), and Horizontal Proximity Probes, Peak (Sh. 3) Minimum (Sh. 4), at 75 kW

3b - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Peak Hold, Silencer Installed, Driveshaft Disconnected

3c - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Peak Hold, Silencer Removed, Driveshaft Disconnected

3d - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Peak Hold, Loading the Combustor Flange with a "2 x 4"

3e - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Peak Hold, Solar Instrumented Tailpipe

3f - Vertical (Sh. 1 and 3) and Horizontal (Sh. 2 and 4) Proximity Probes, Peak Hold, 75 kW (Sh. 1 and 2 damped, Sh. 3 and 4 undamped)

3g - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Peak Hold, 75 kW, Bellows Panel Installed in Final Configuration.

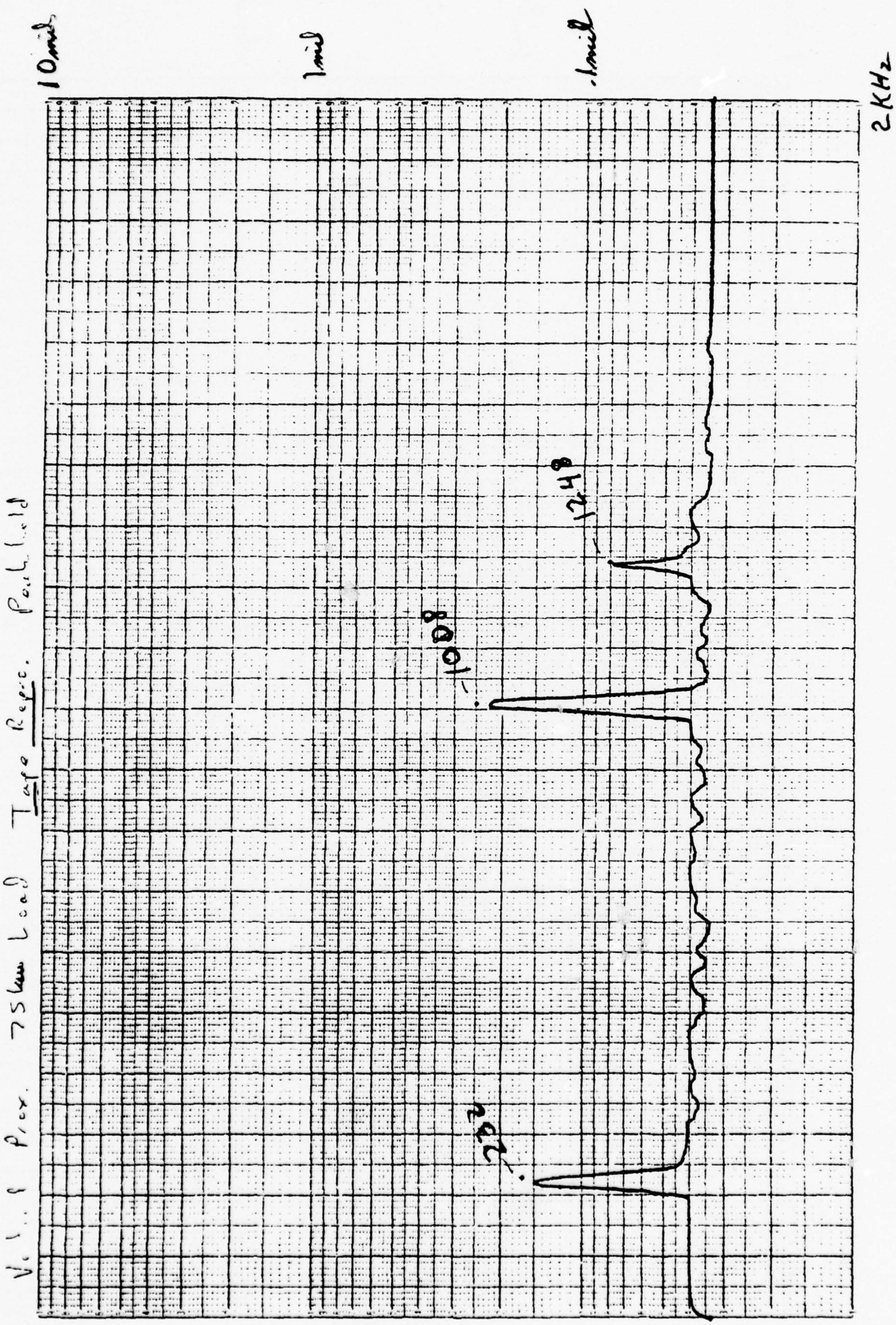


Figure 3a, Sheet 1

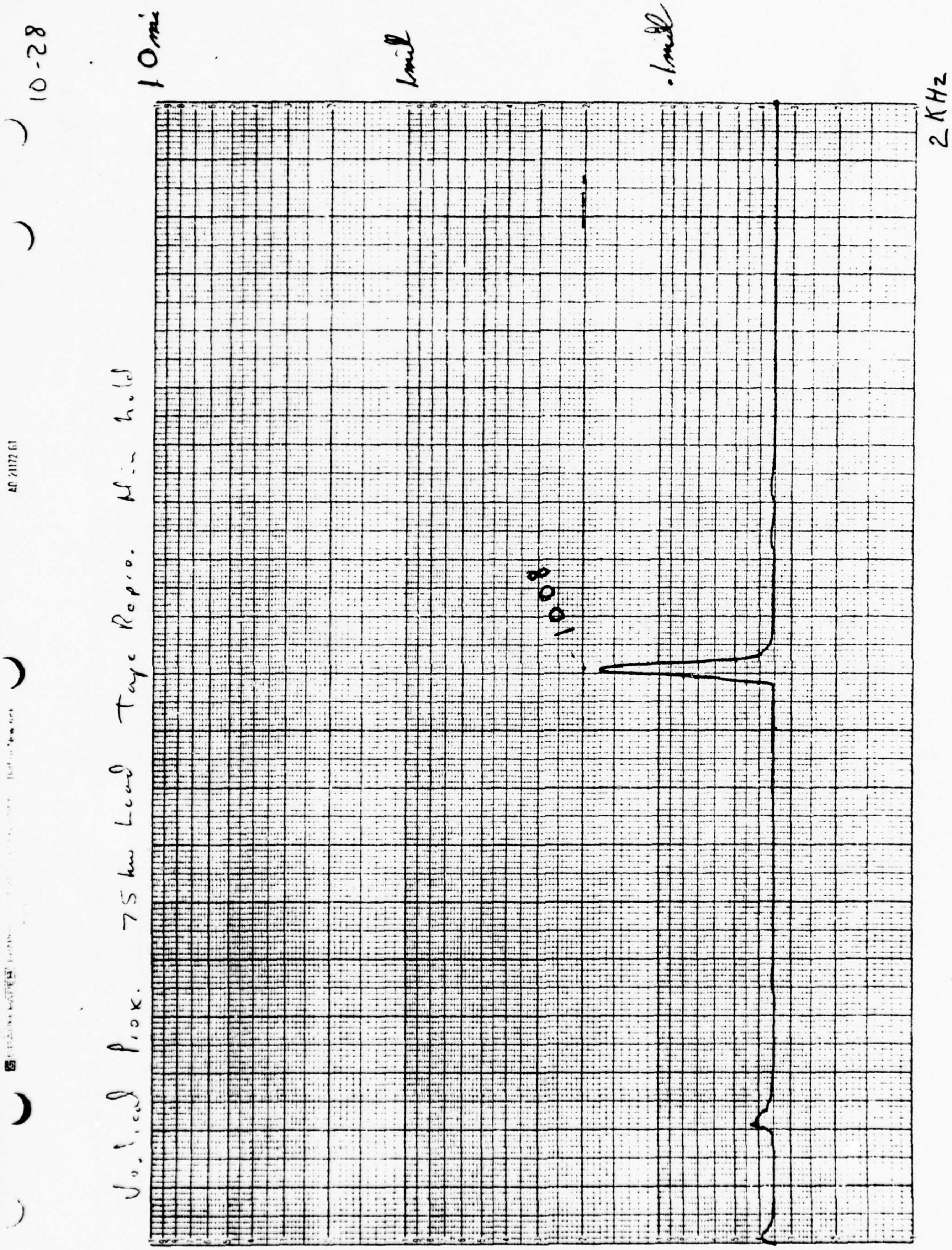
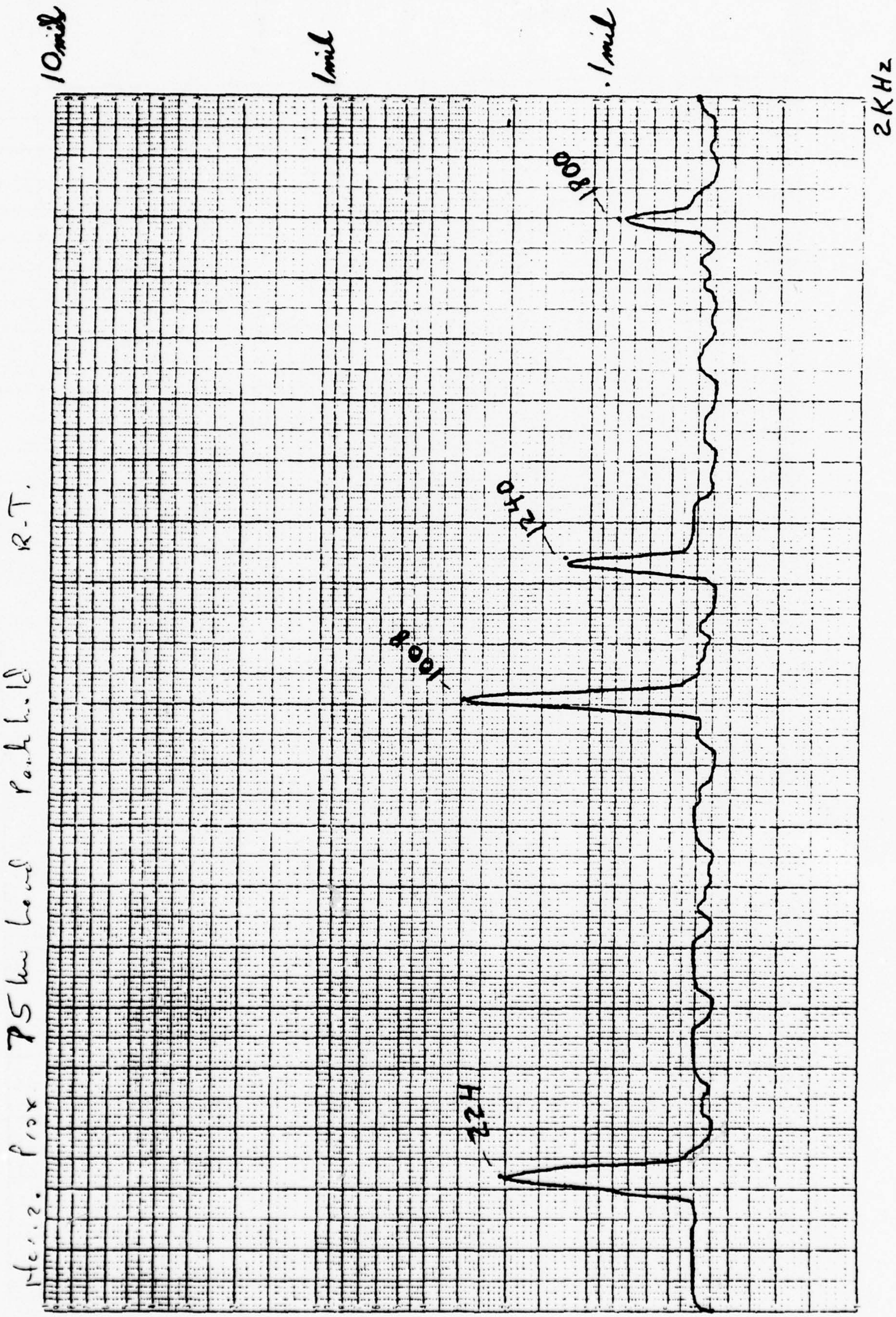


Figure 3a, Sheet 2



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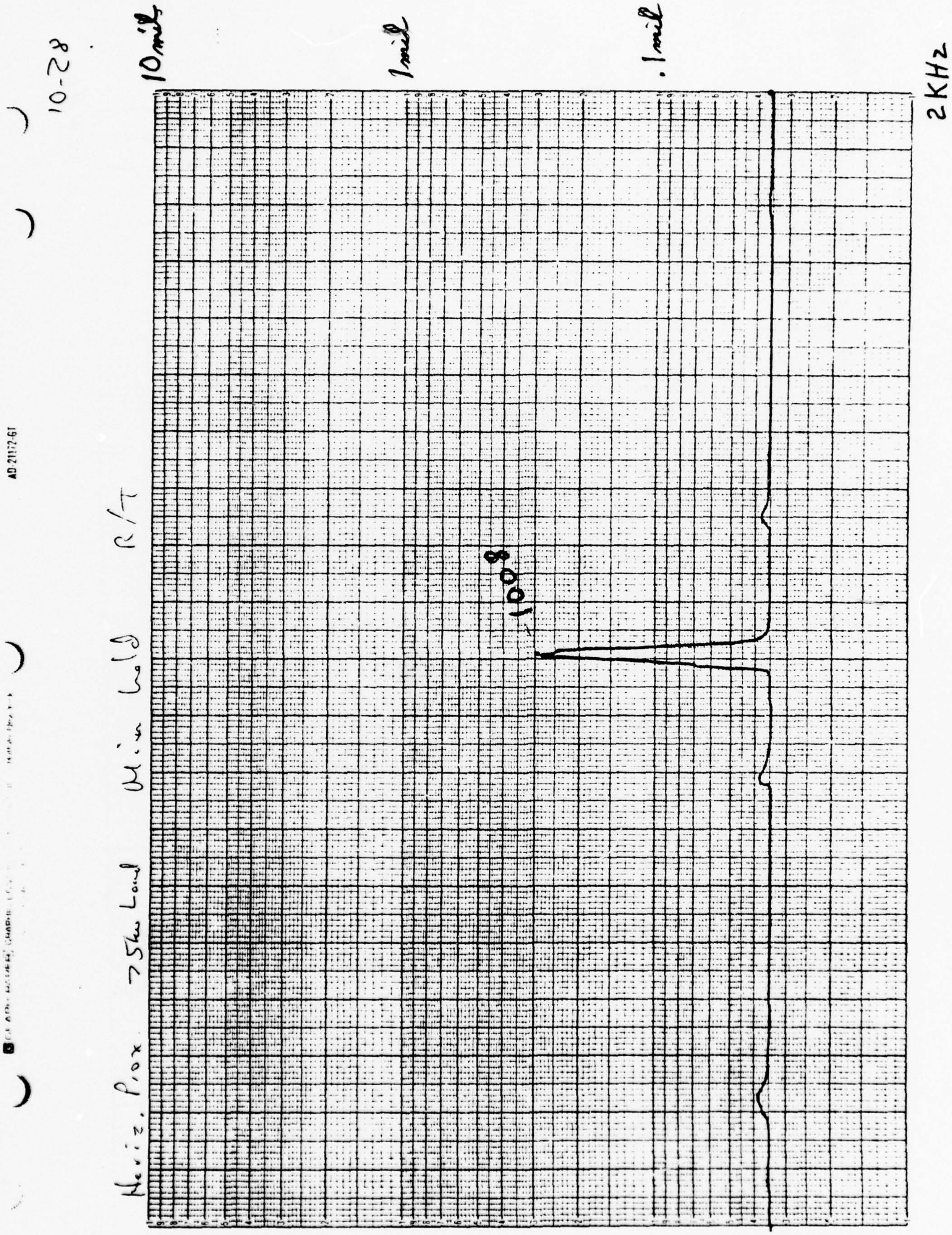


Figure 3a, Sheet 4

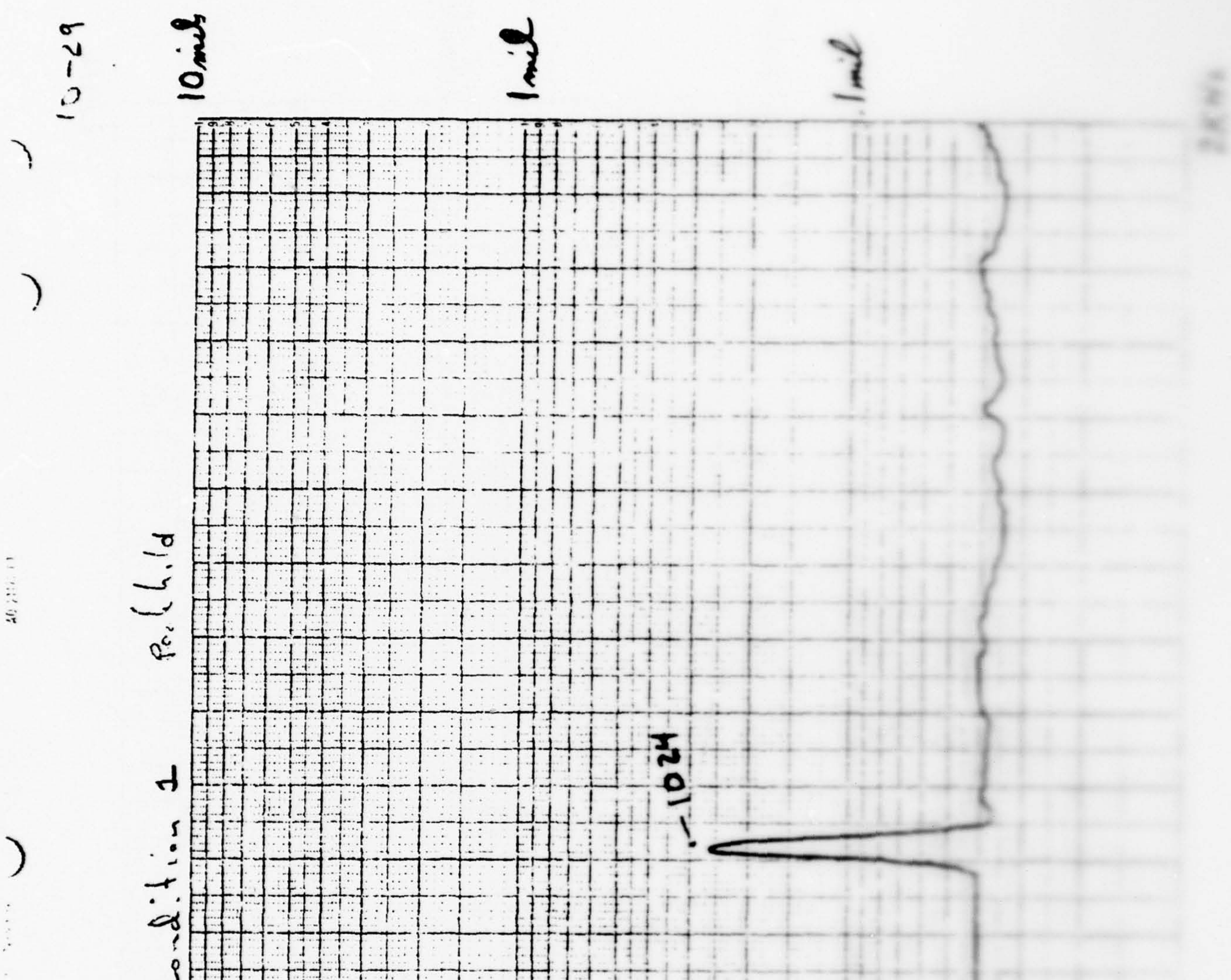


Figure 3b, Sheet 1

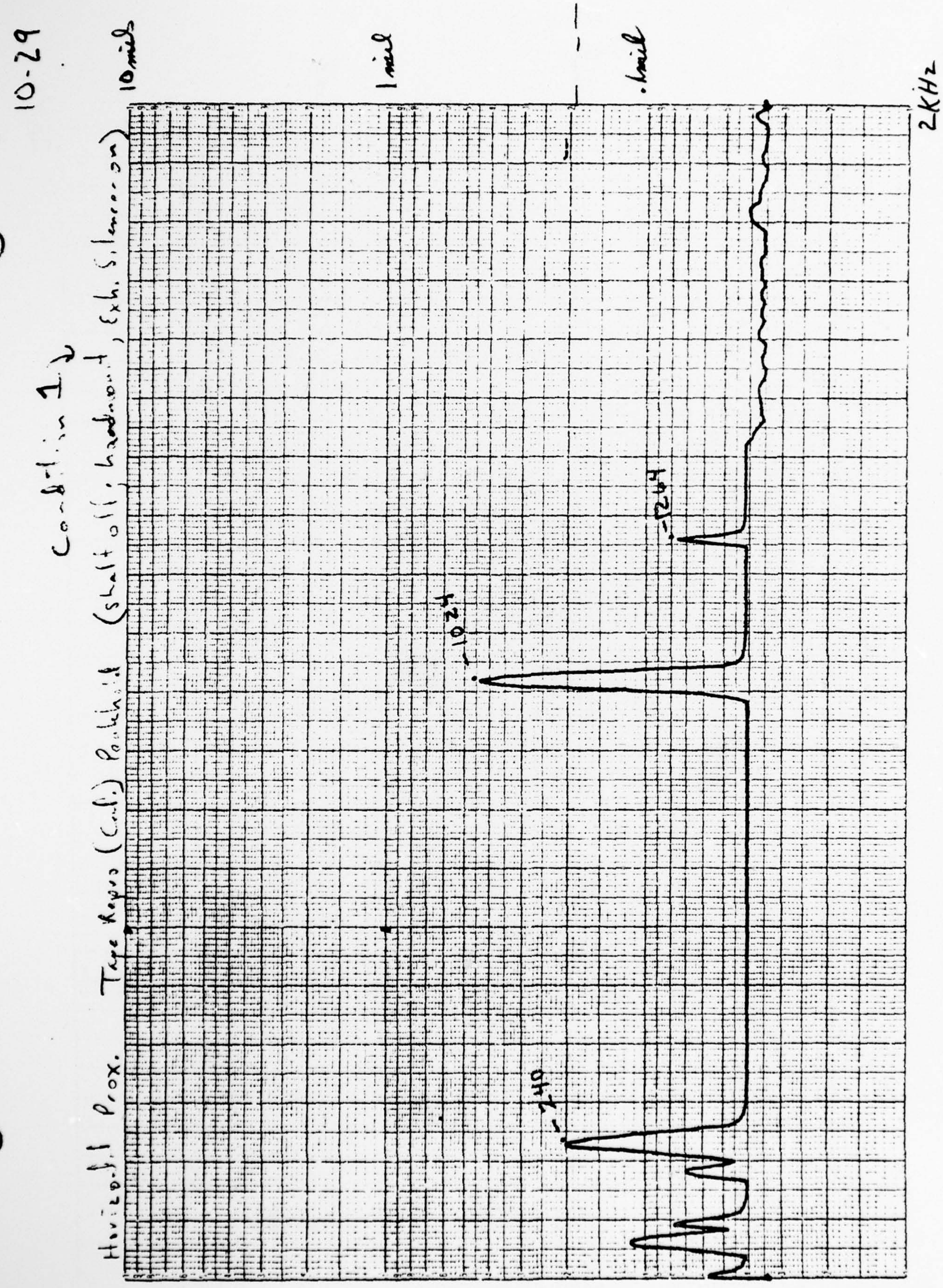
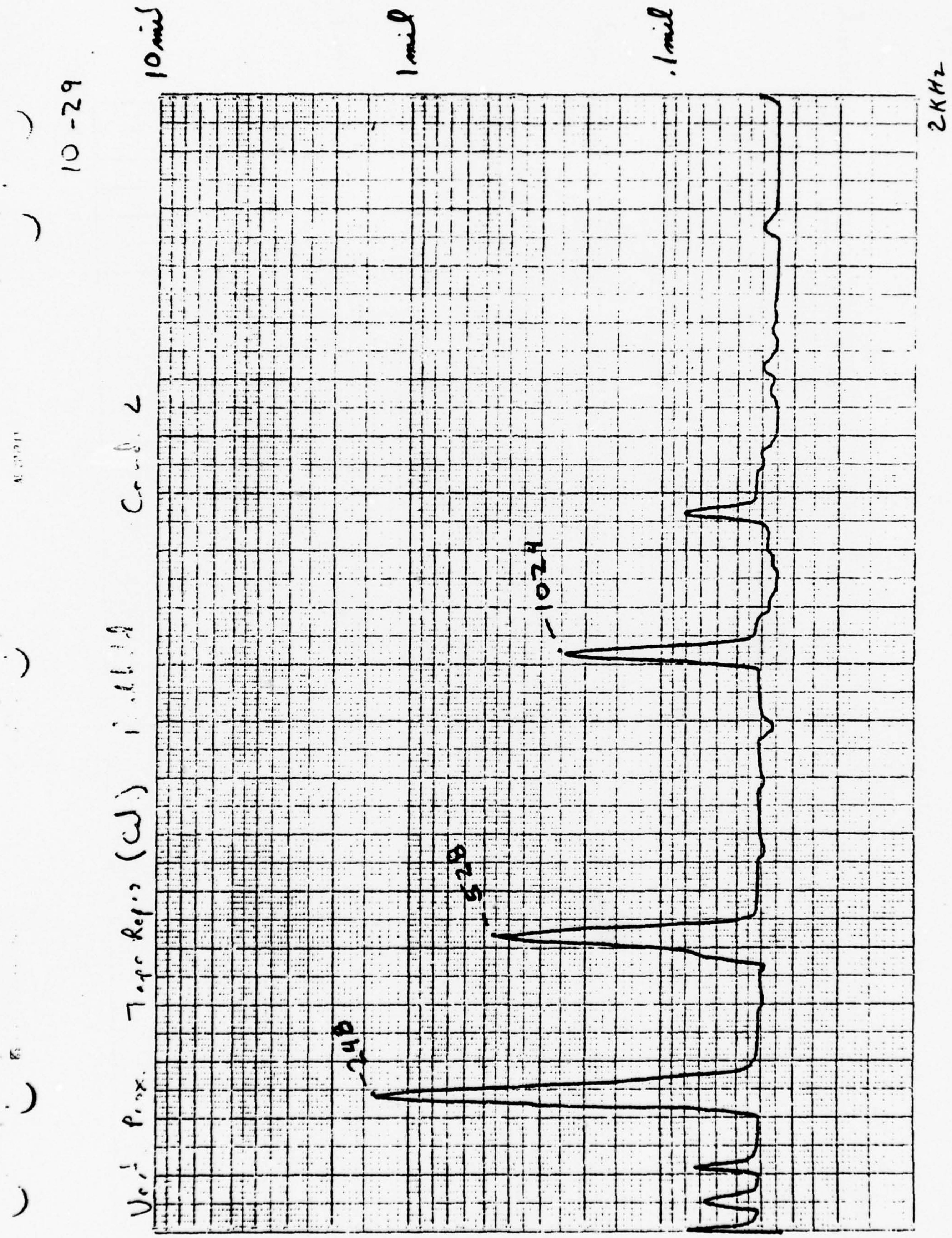


Figure 3b, Sheet 2



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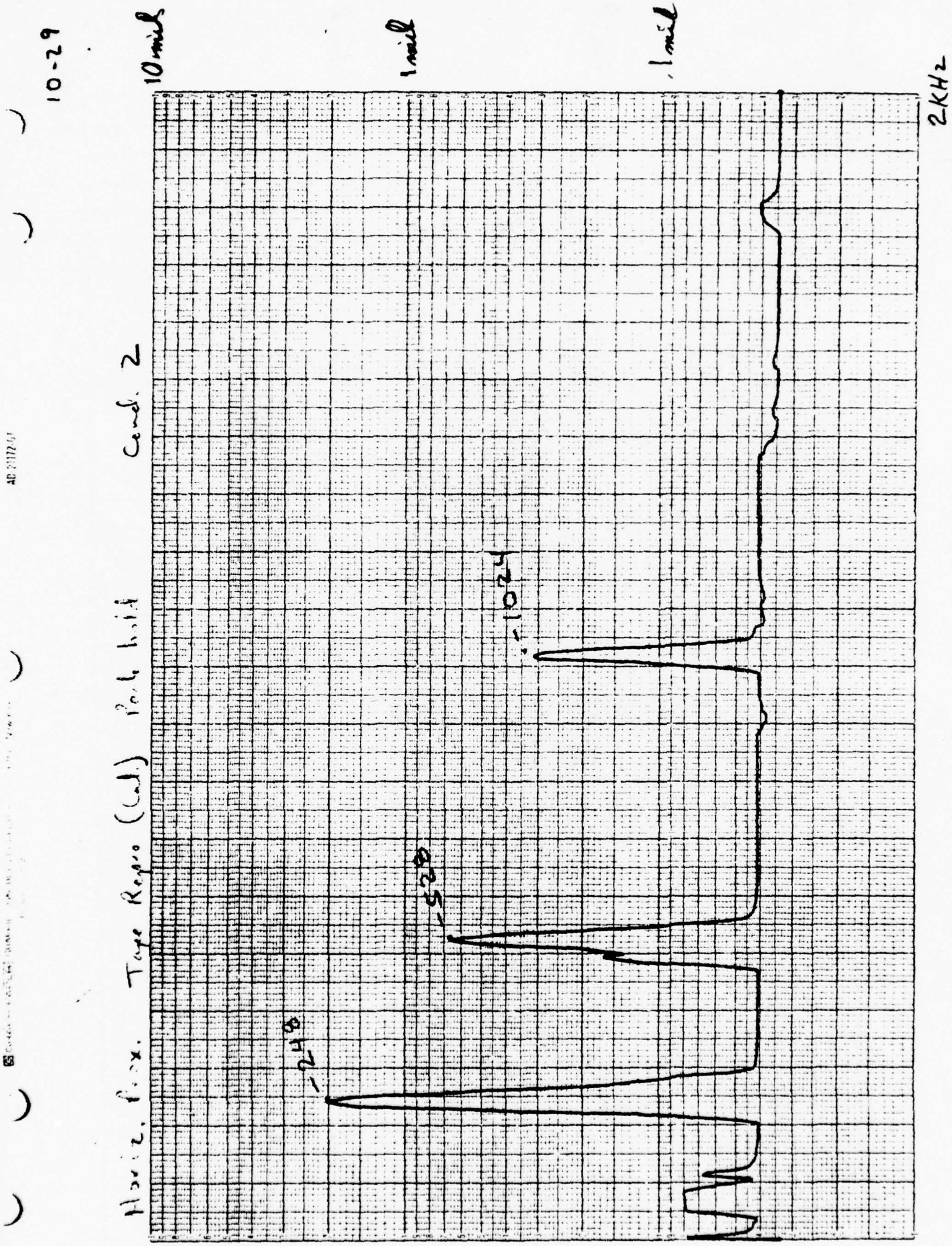

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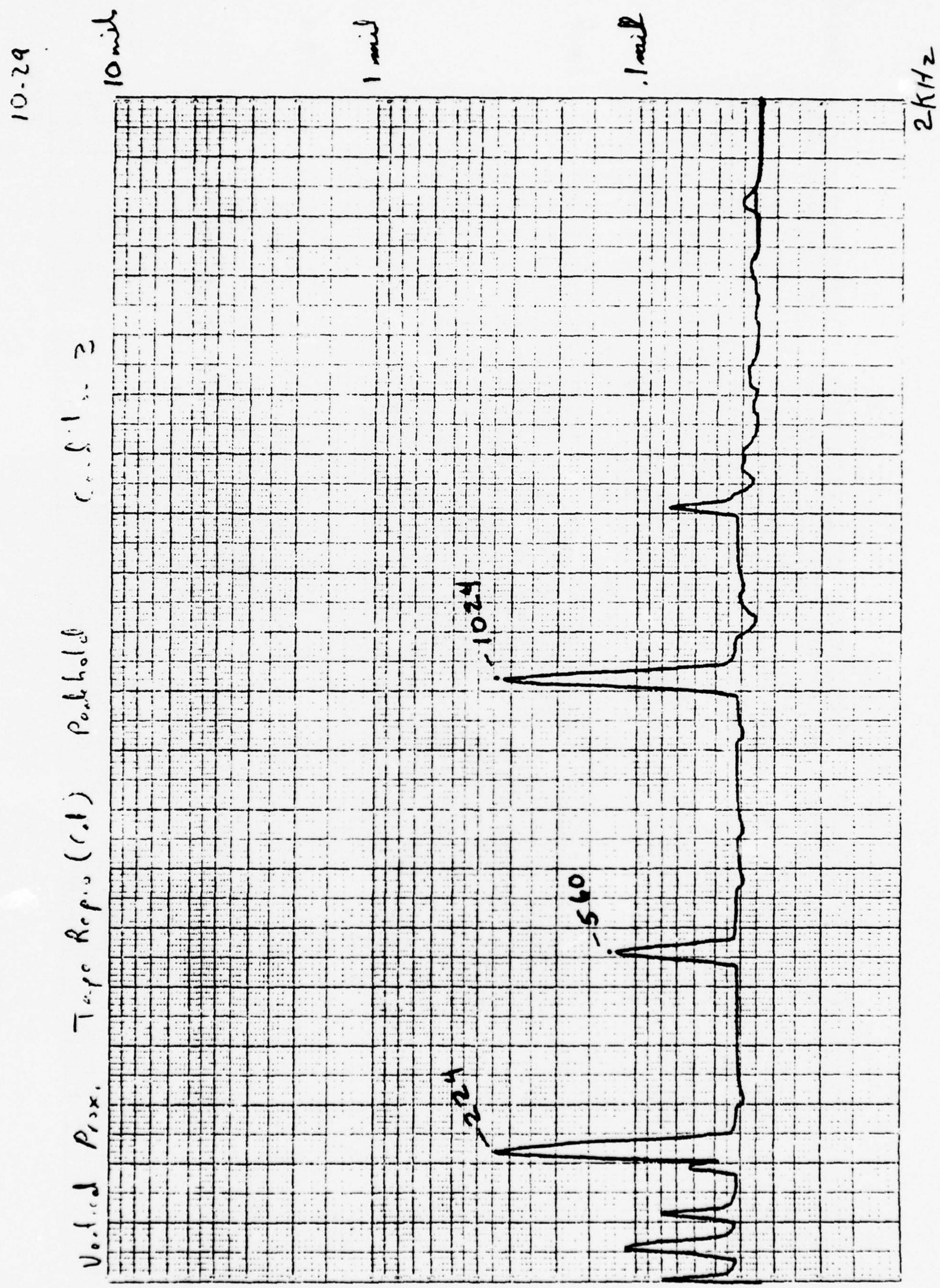
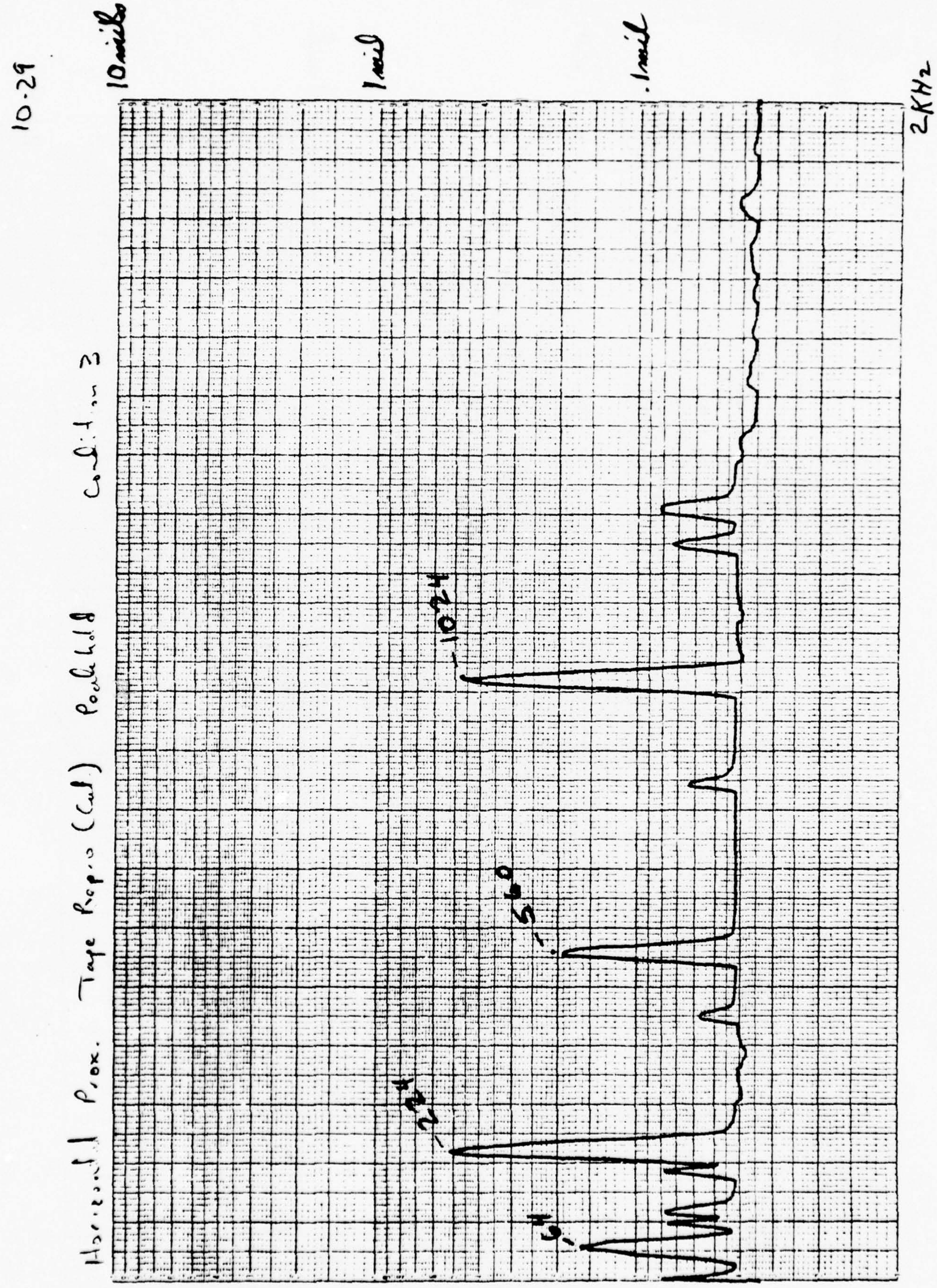


Figure 3d, Sheet 1



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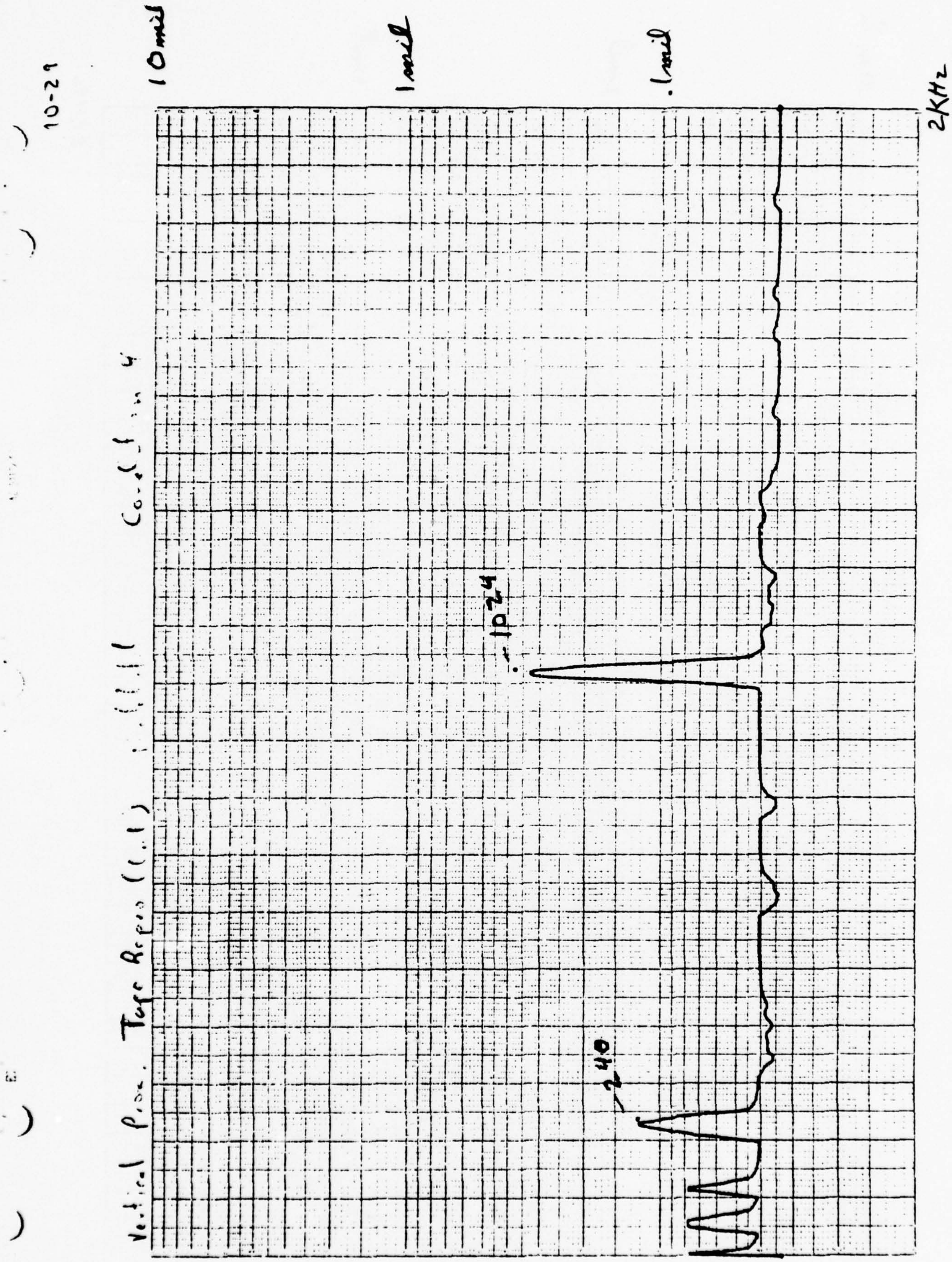
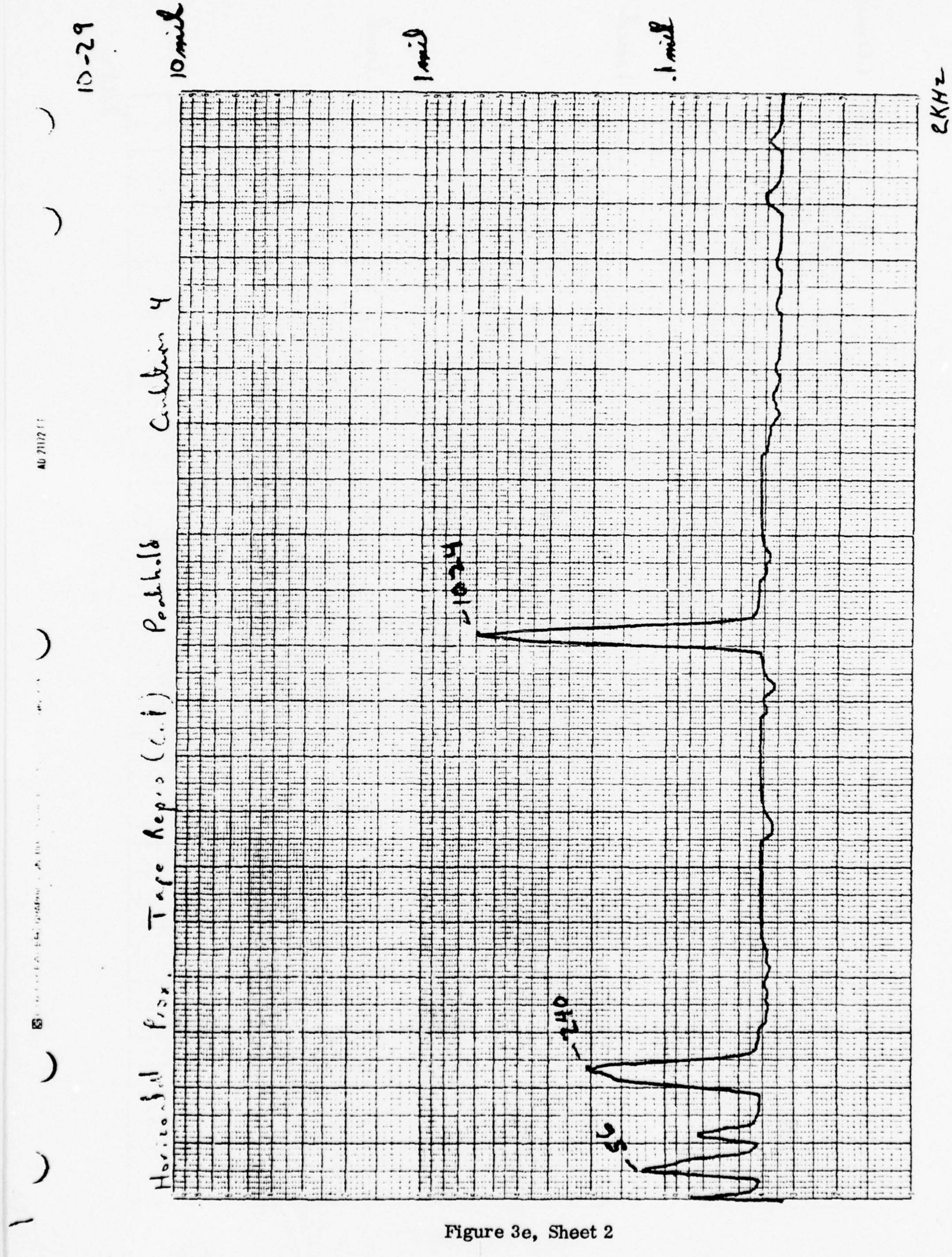


Figure 3e, Sheet 1



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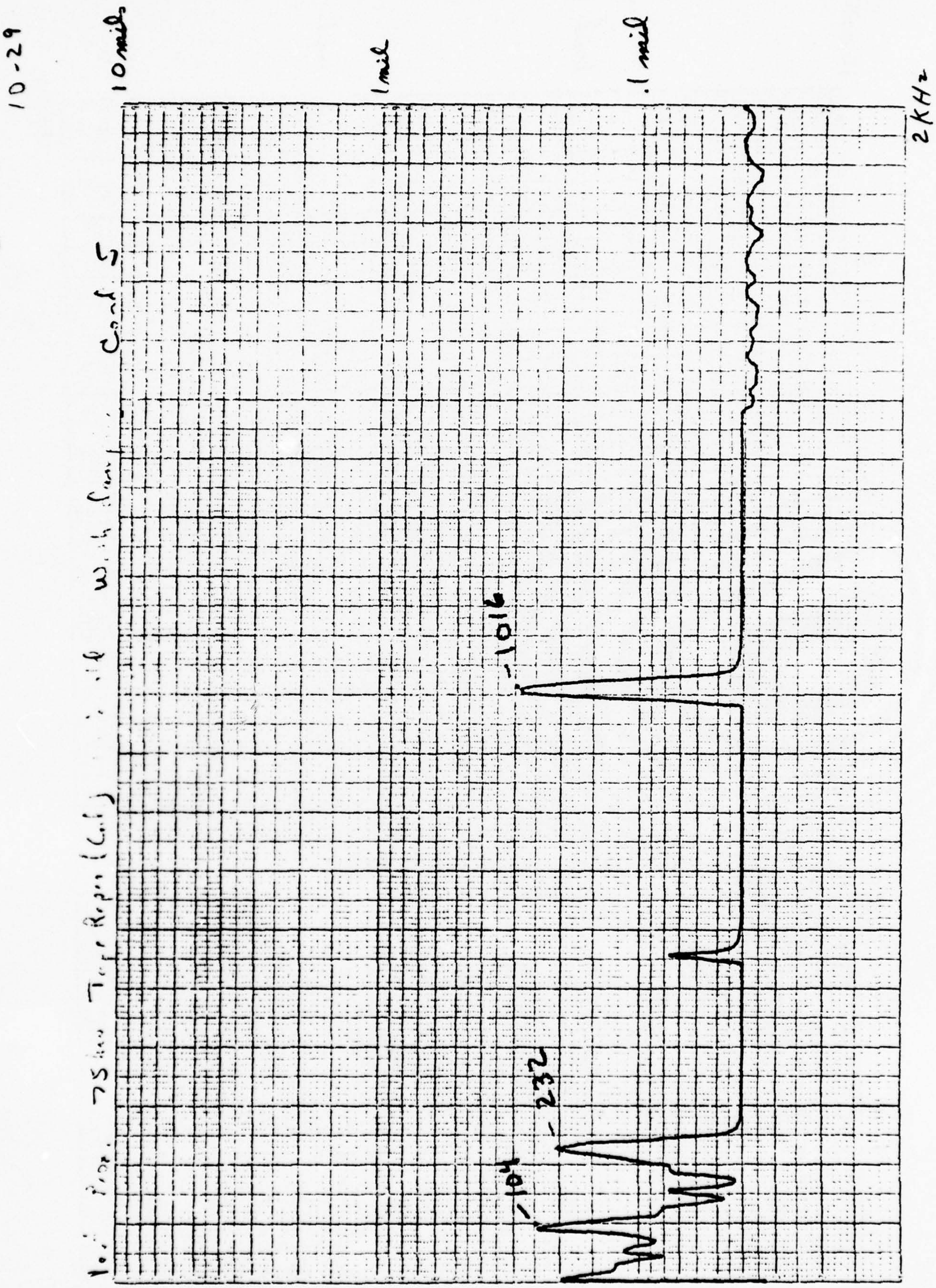
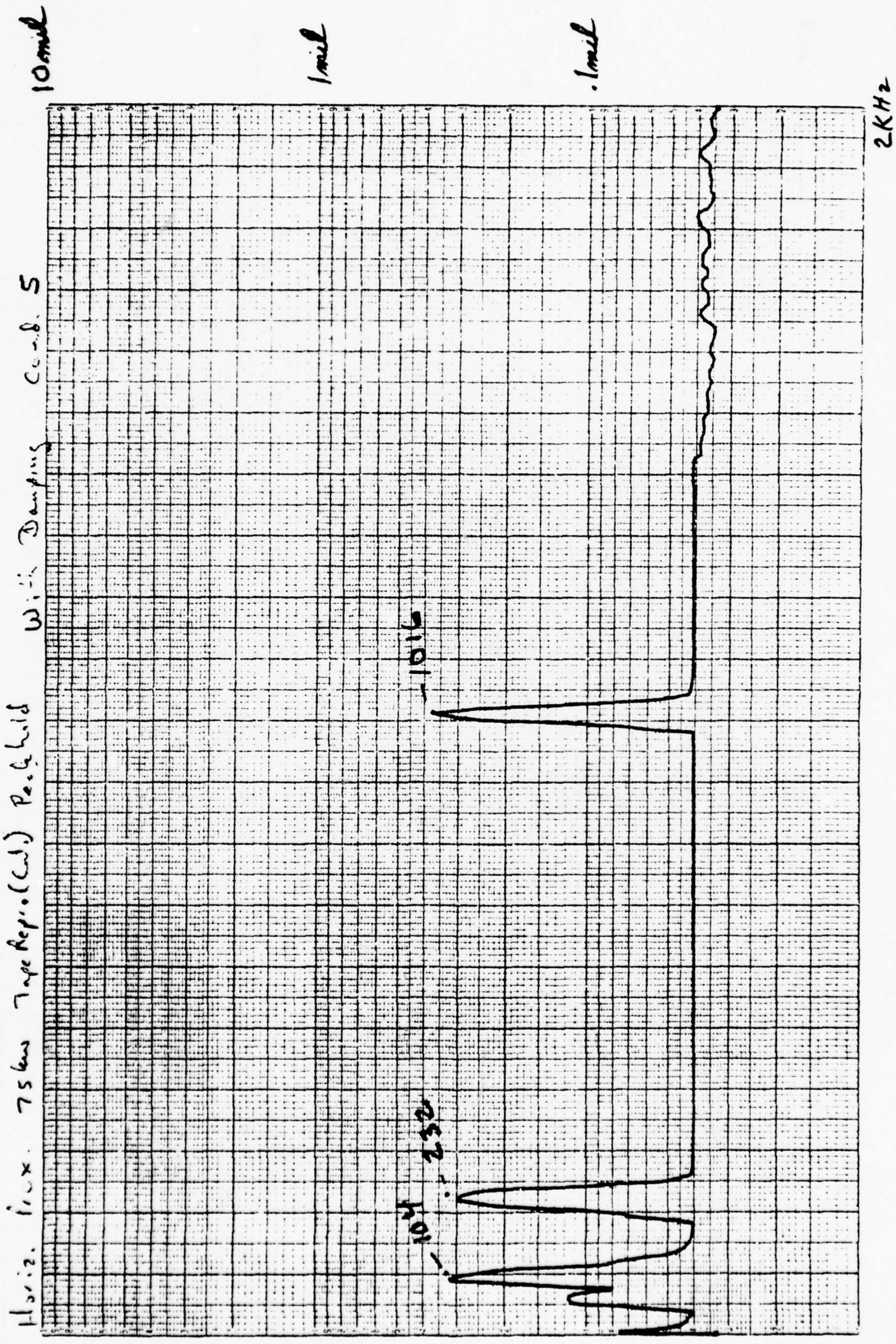


Figure 3f, Sheet 1



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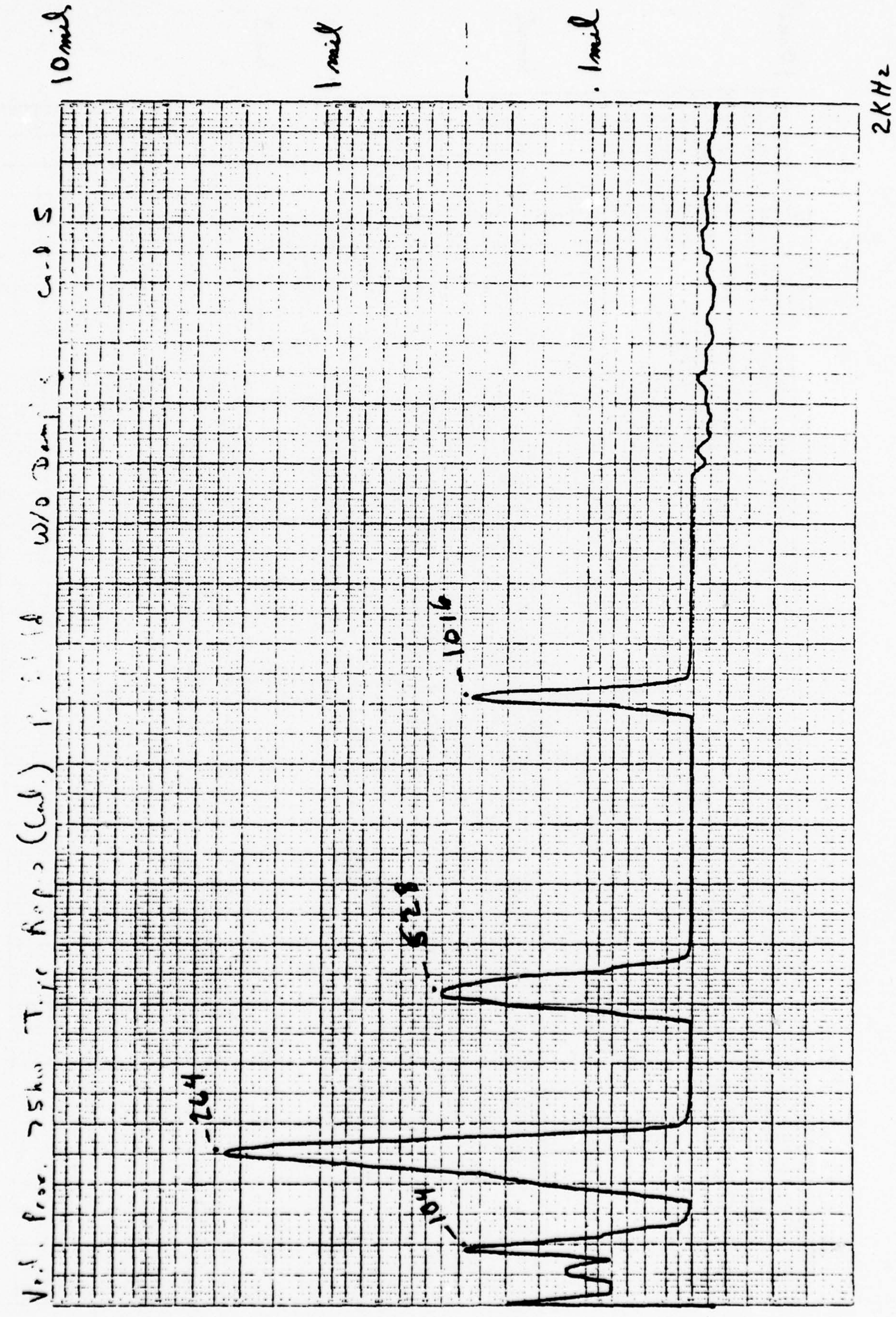

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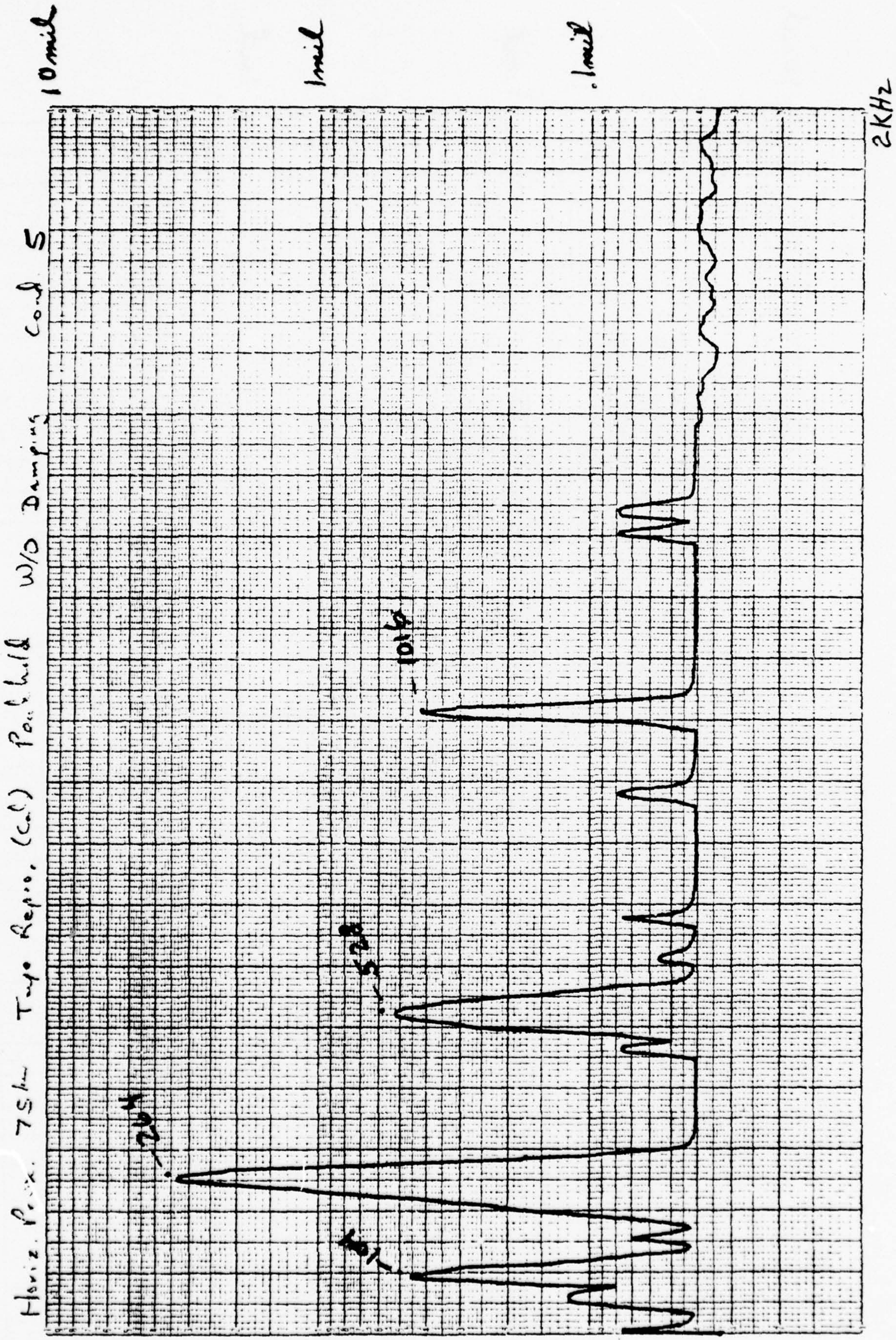

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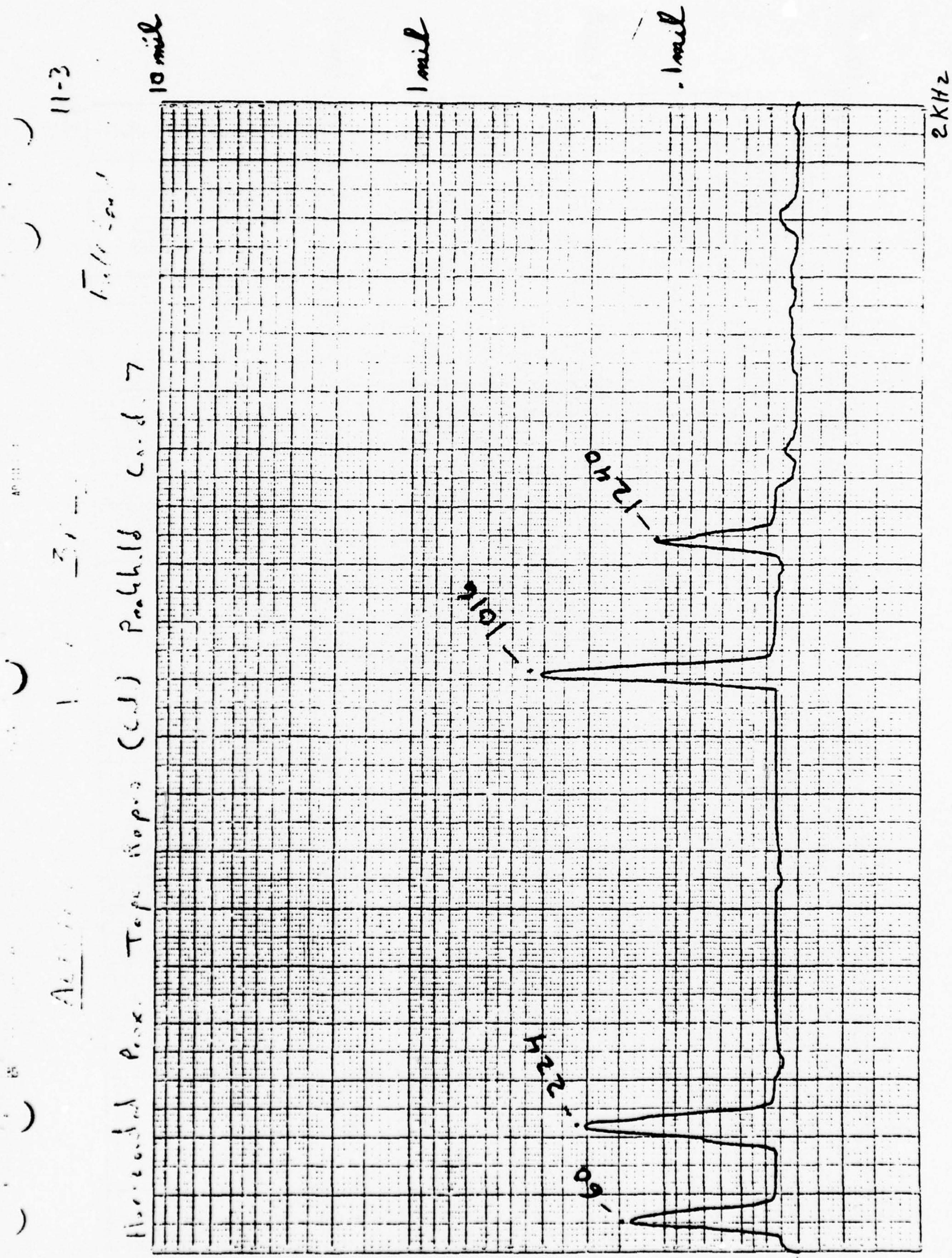


Figure 3g, Sheet 1

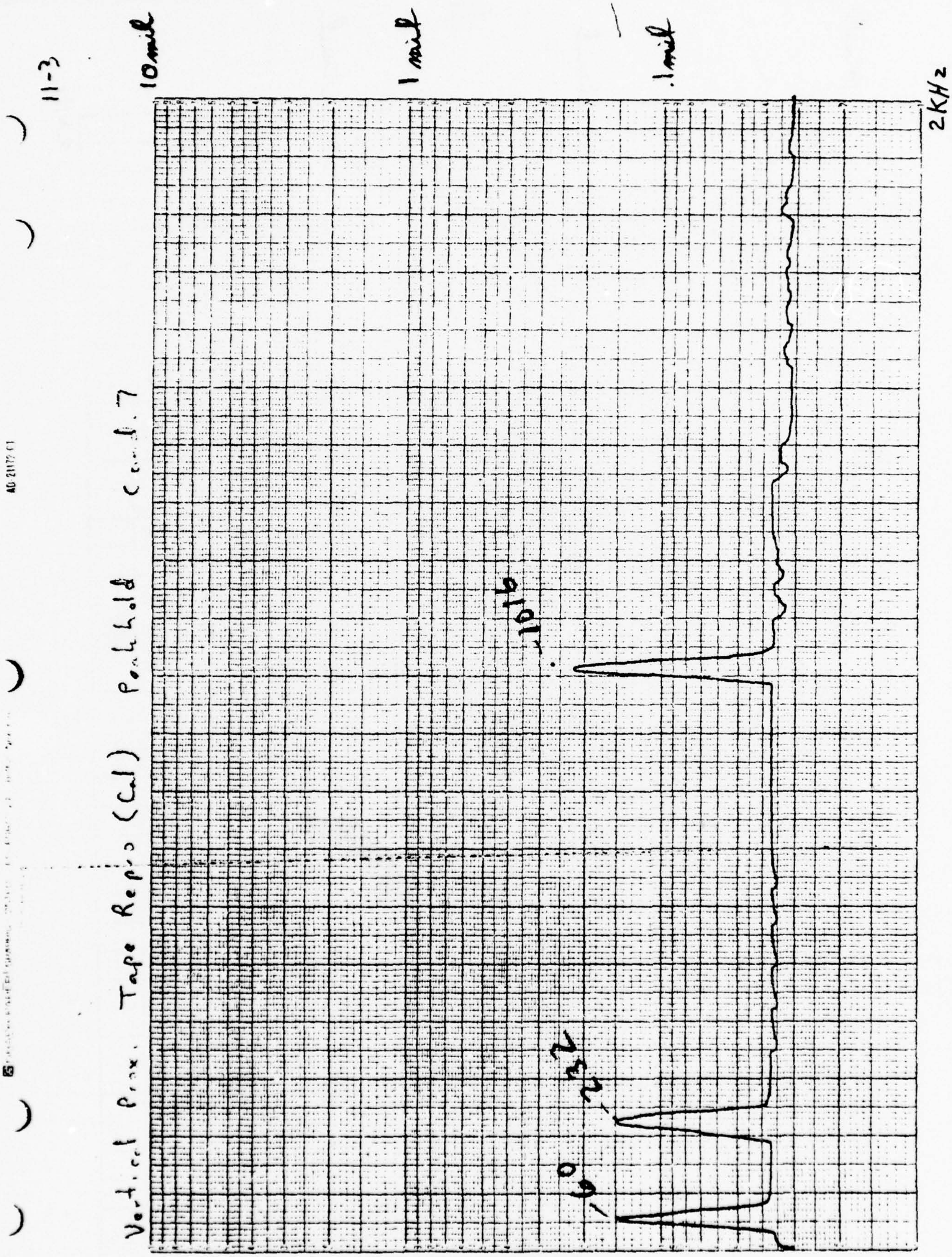


Figure 3g, Sheet 2

APPENDIX C

SECTION 4

ENGINE S/N 750228 AT SOLAR
AFTER INSPECTION AND BEARING REPLACEMENT

4a - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, 0 kW, Tailpipe On

4b - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, 0 kW, Tailpipe Off

4c - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, 0 kW, Tailpipe On, Second Bearing

4d - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, 0 kW, Tailpipe Off, Second Bearing

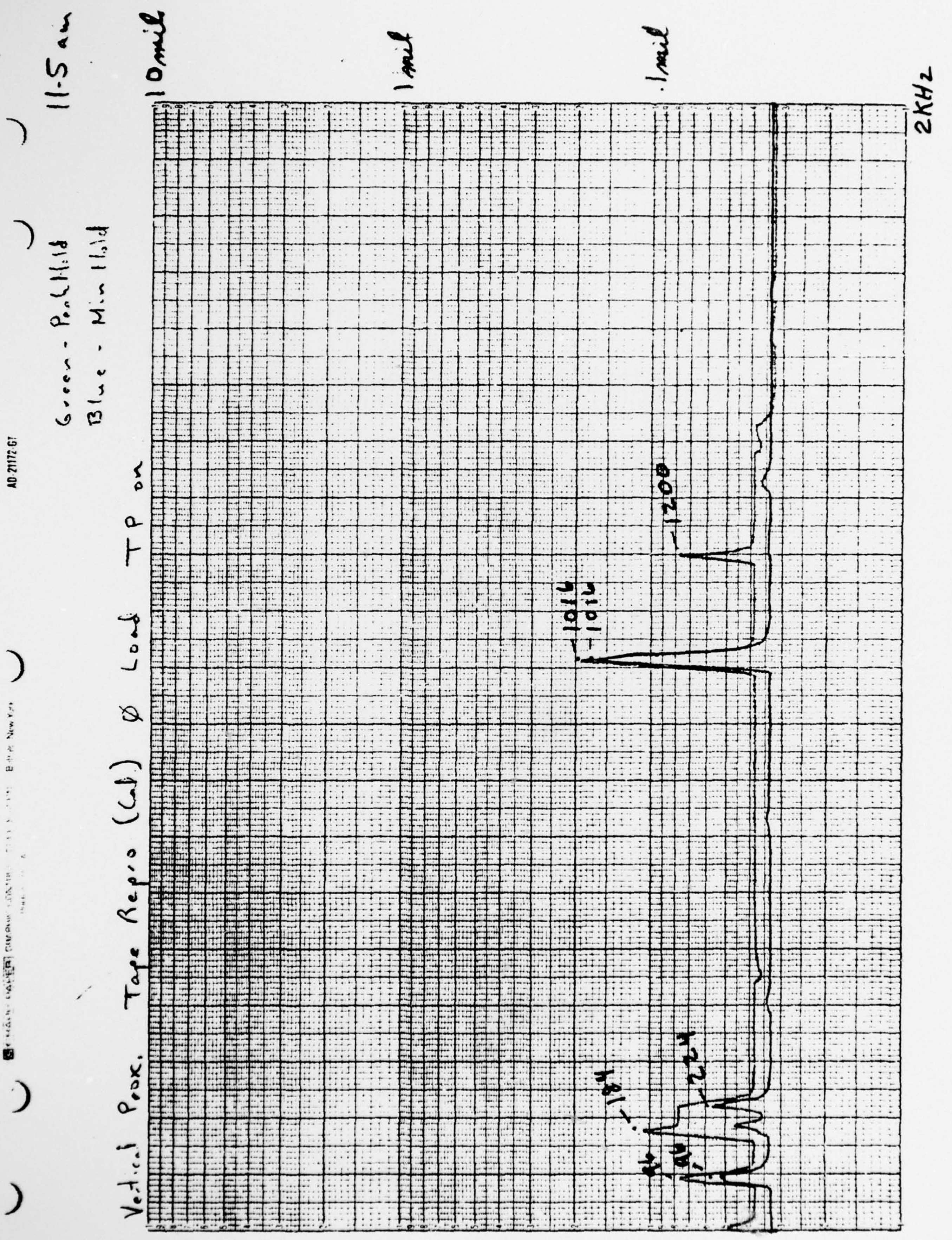


Figure 4a, Sheet 1

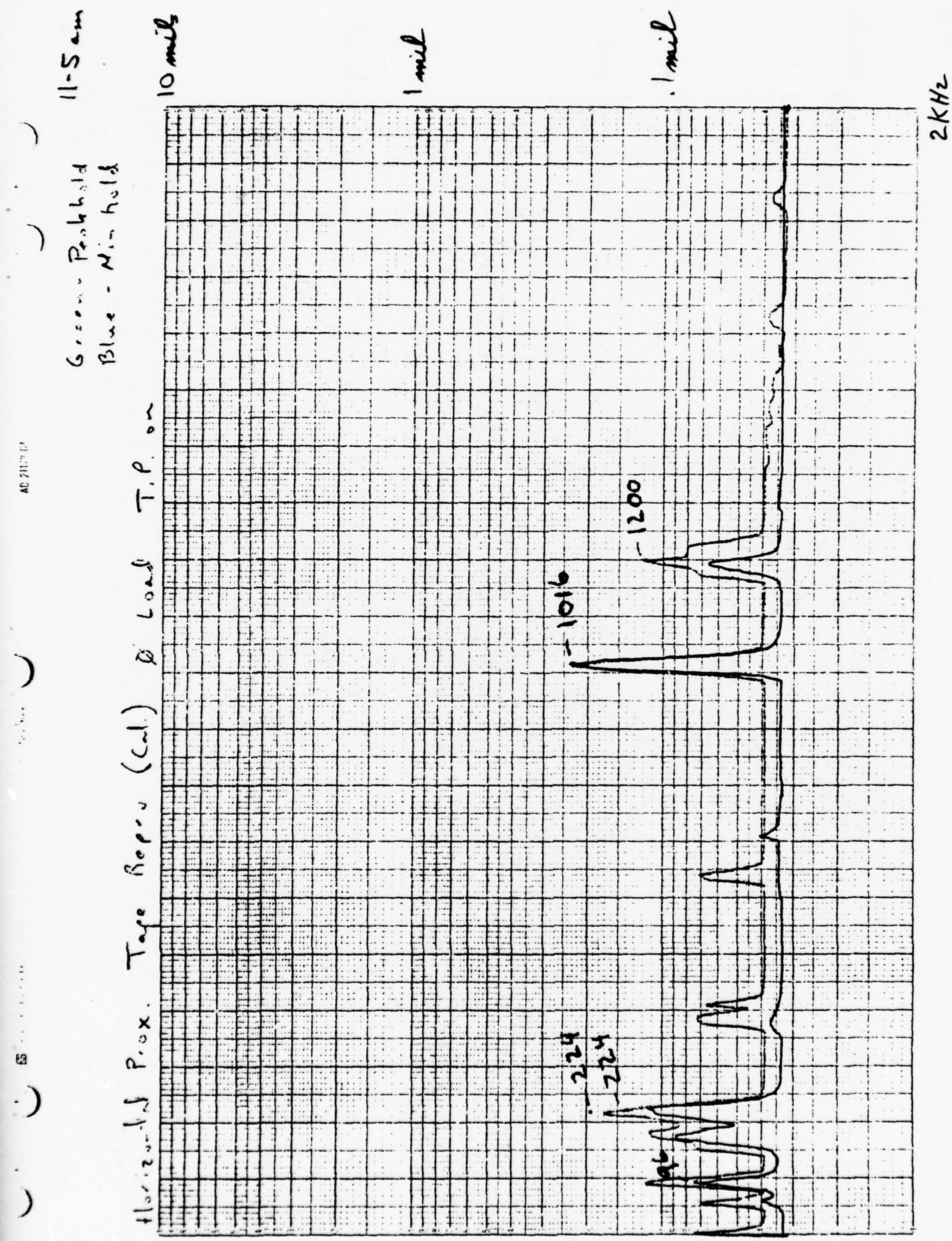
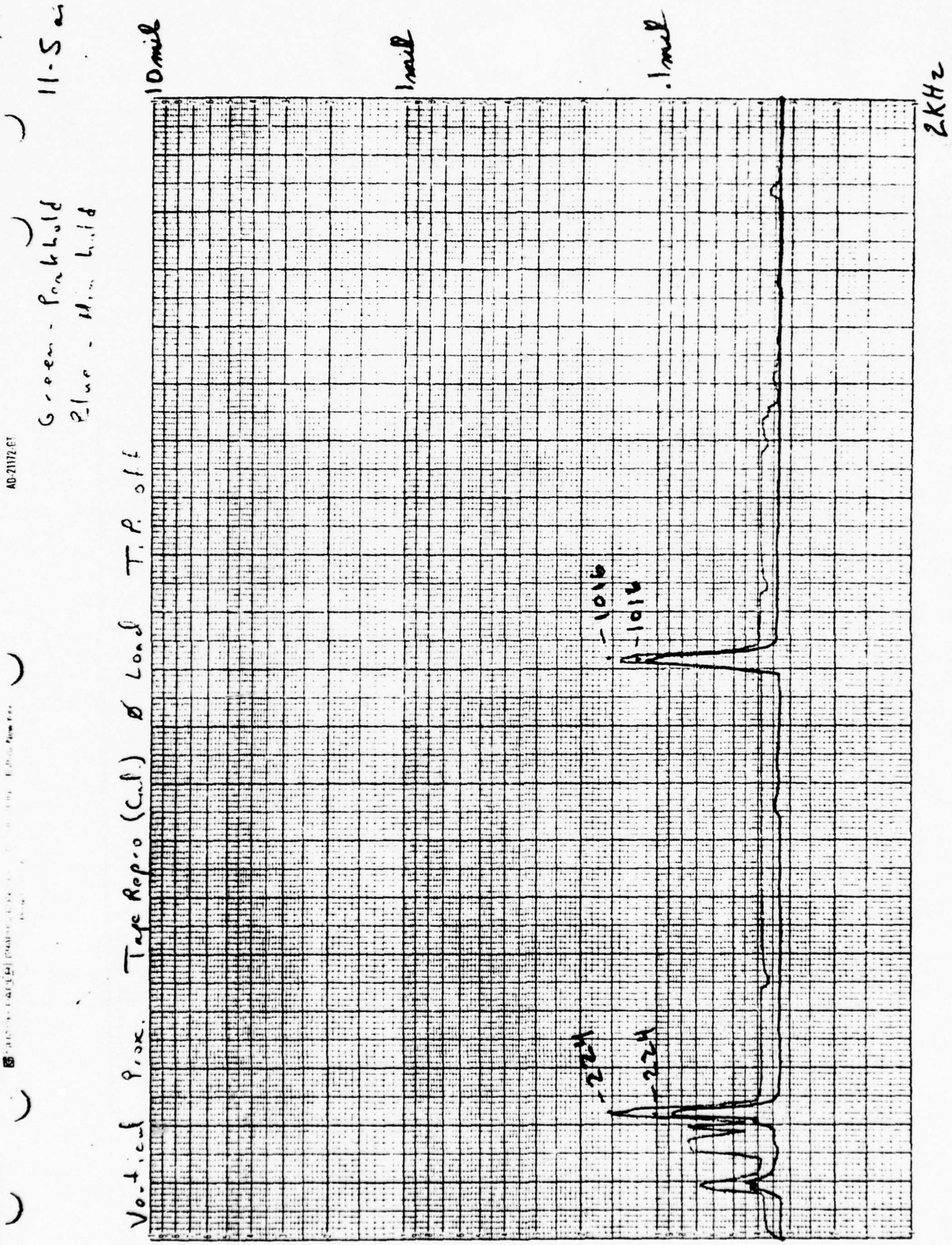


Figure 4a, Sheet 2



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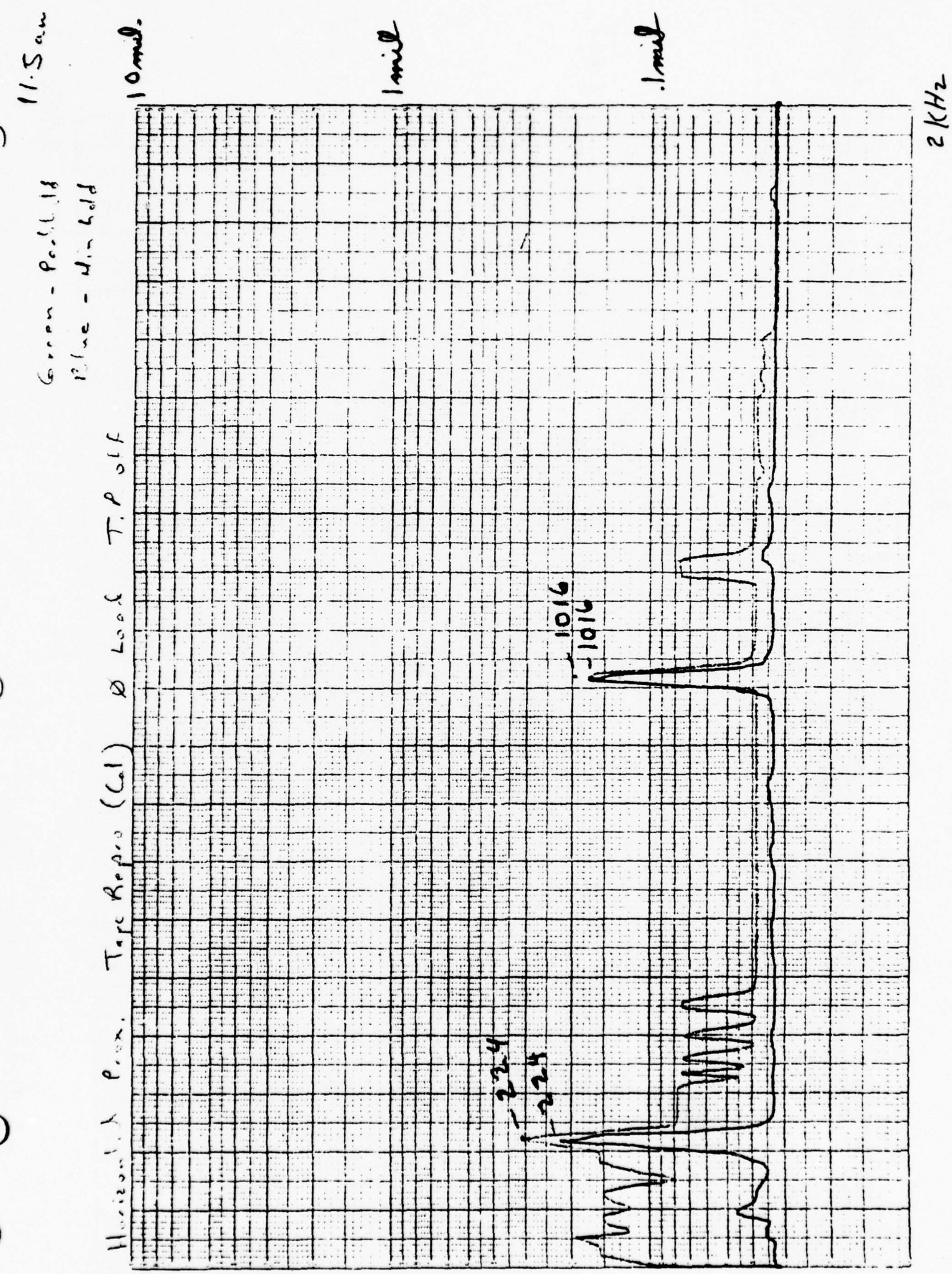

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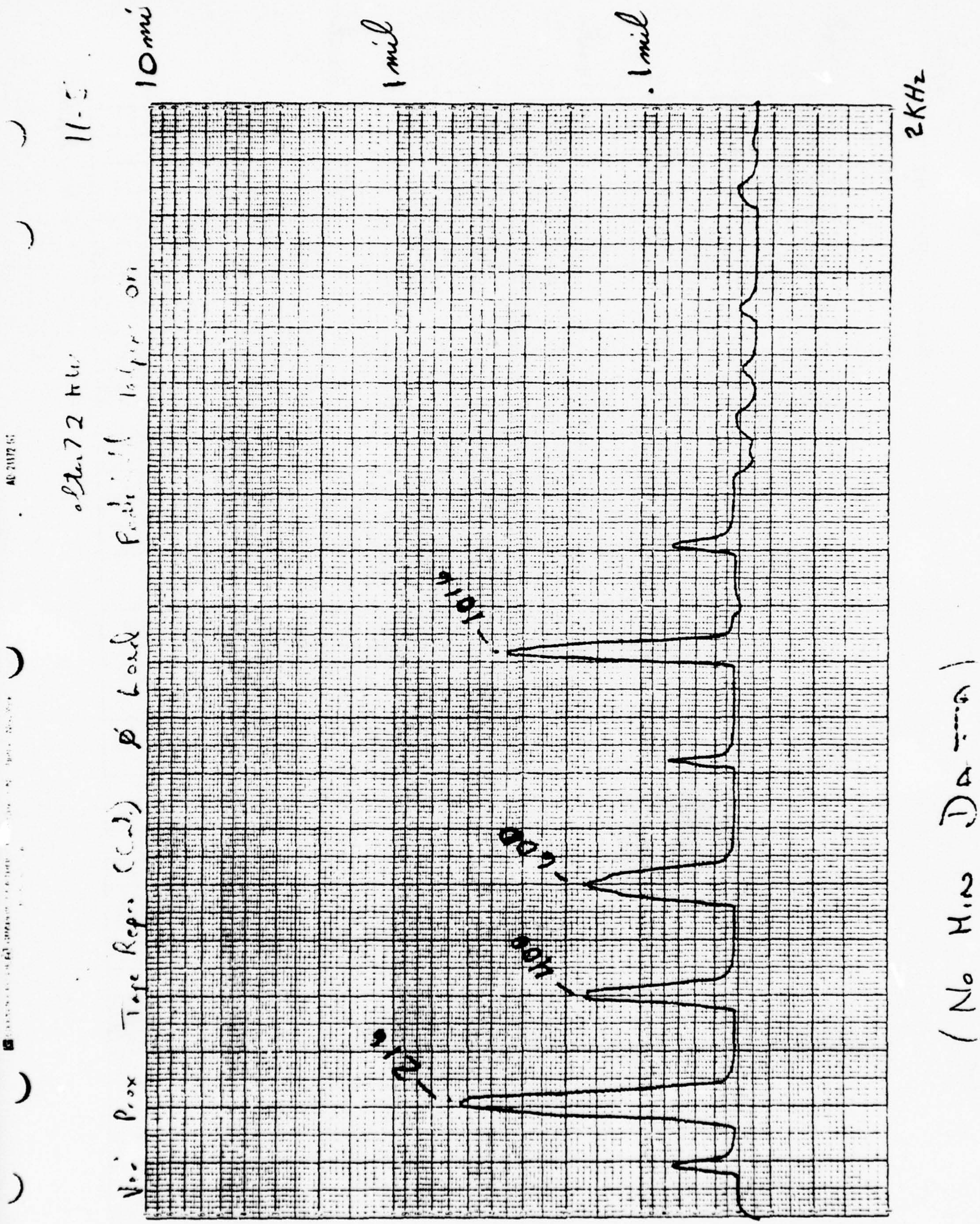


Figure 4c, Sheet 1

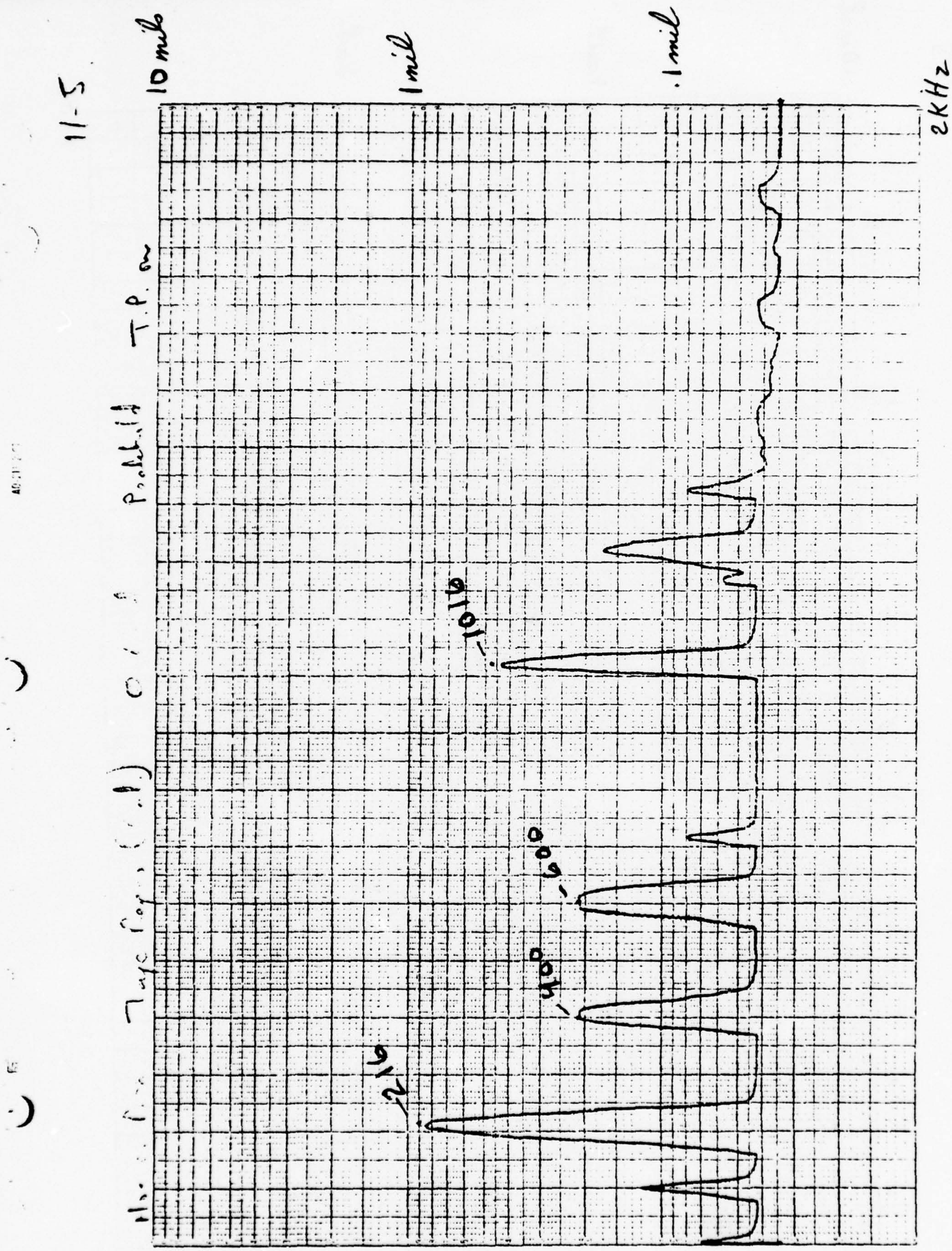


Figure 4c, Sheet 2

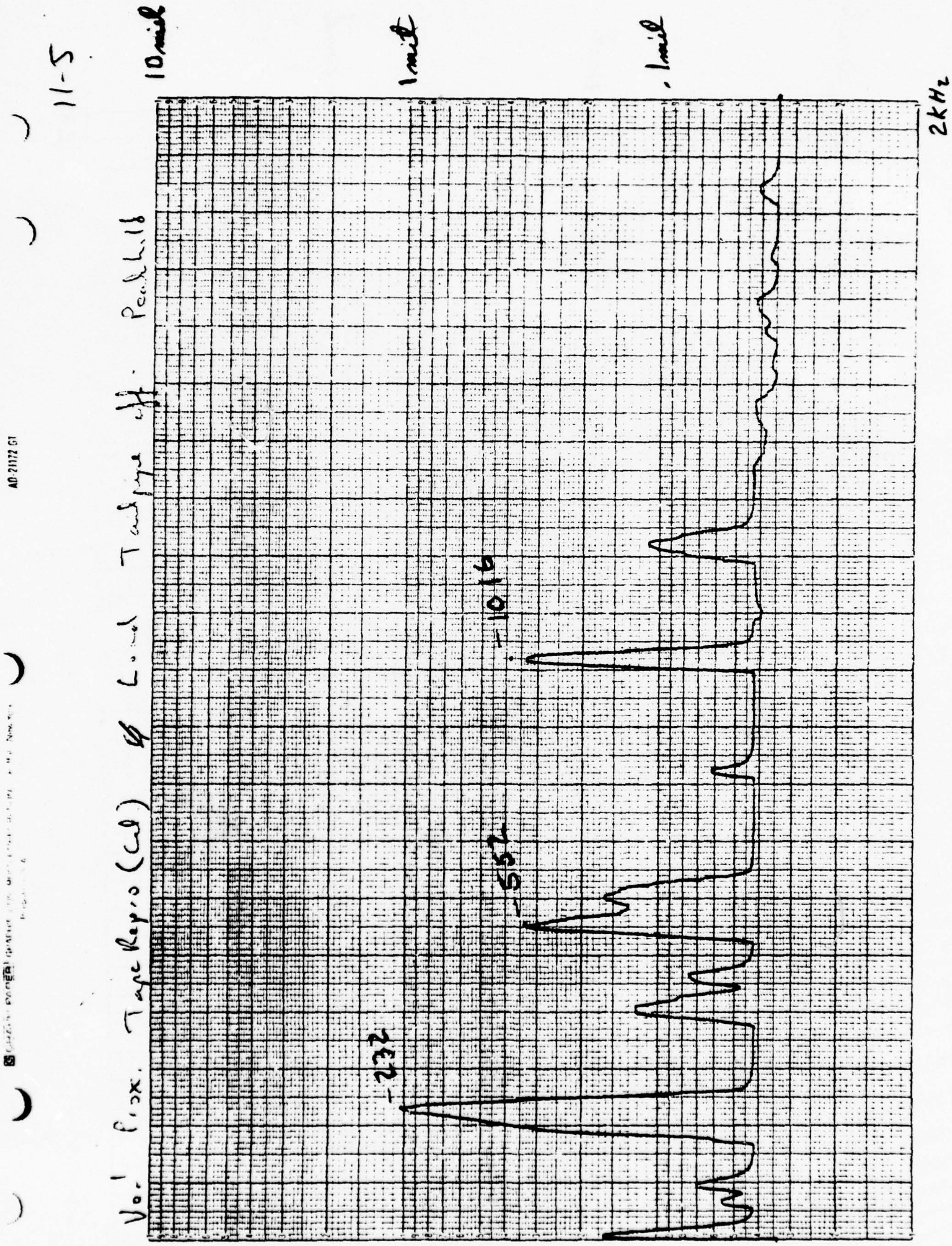


Figure 4d, Sheet 1

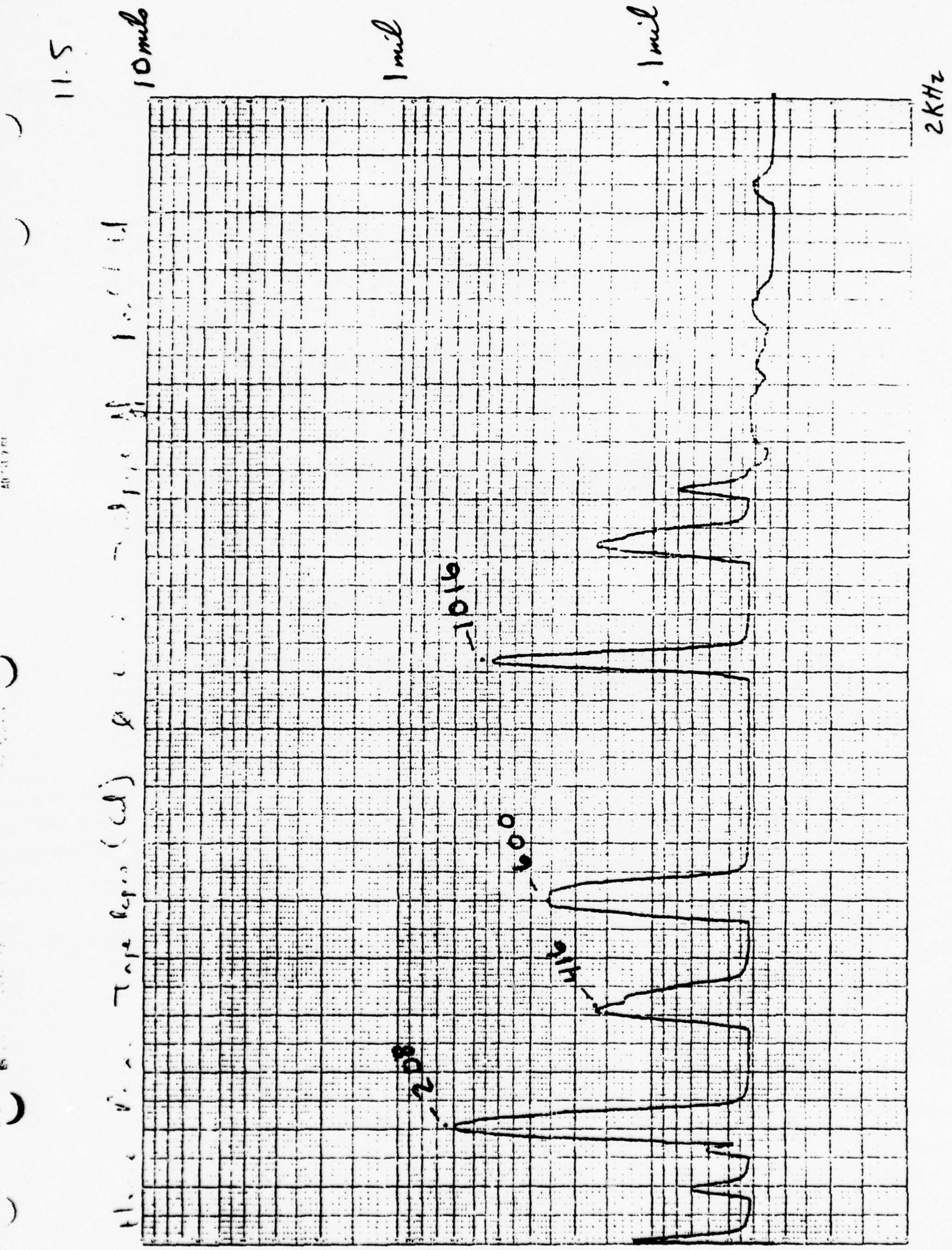


Figure 4d, Sheet 2

APPENDIX C

SECTION 5

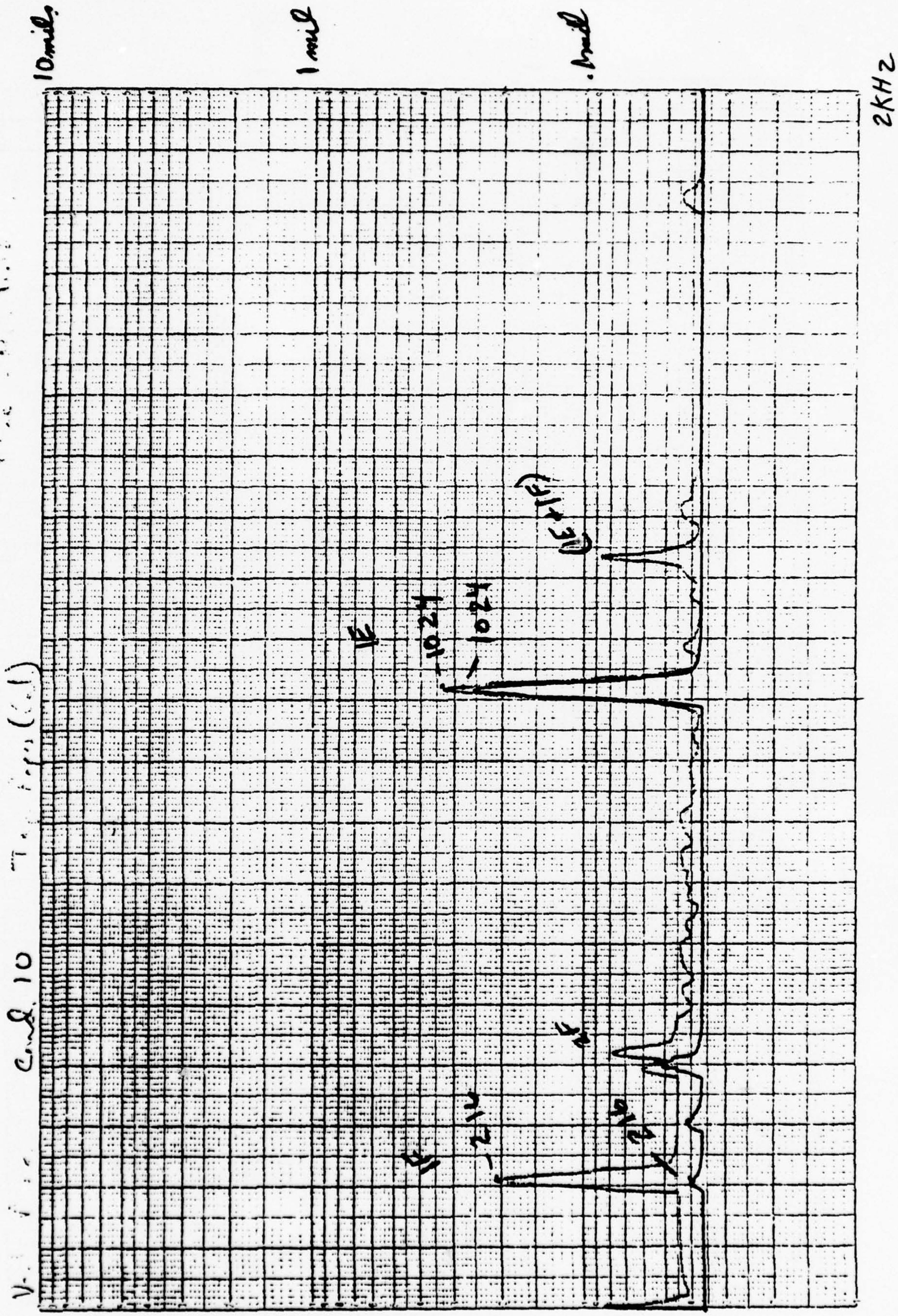
ENGINE S/N 750228 AT FORT STORY
ABOARD LACV-30-1

5a - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Bellows Panel On, Driveshaft Off

5b - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Bellows Panel Off, Driveshaft Off

5c - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Bellows Panel Off, Driveshaft On

5d - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Bellows Panel On, Driveshaft On



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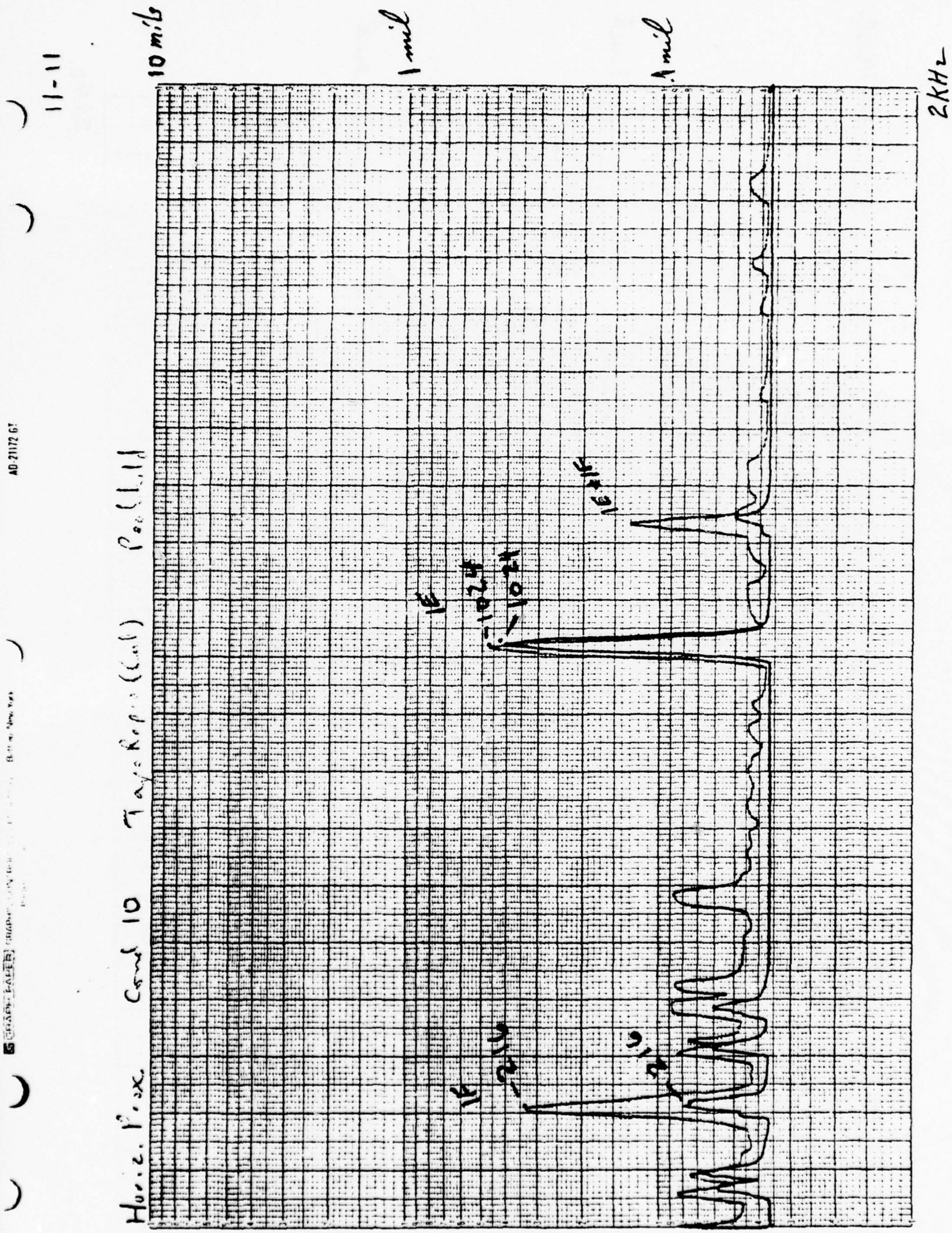

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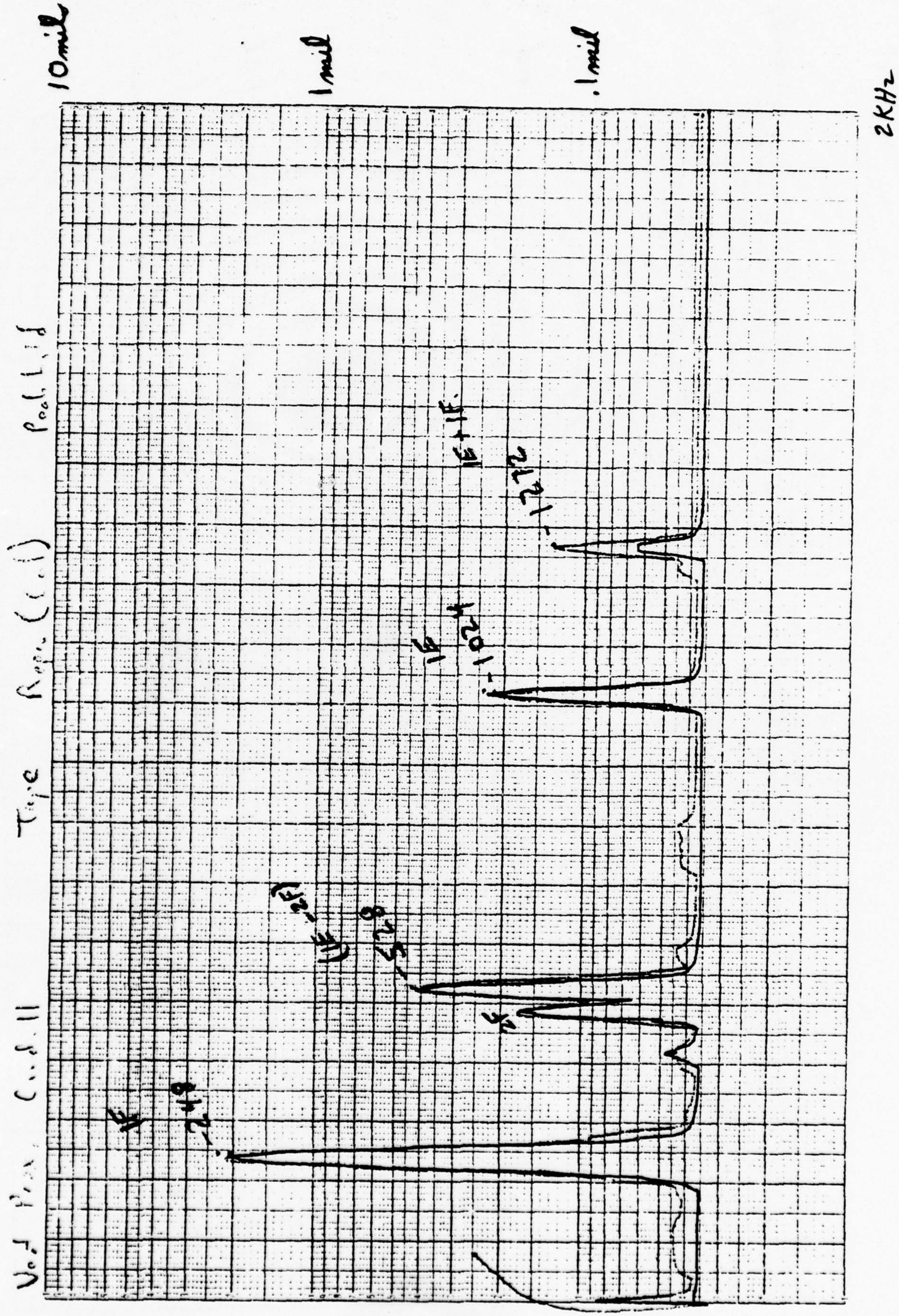
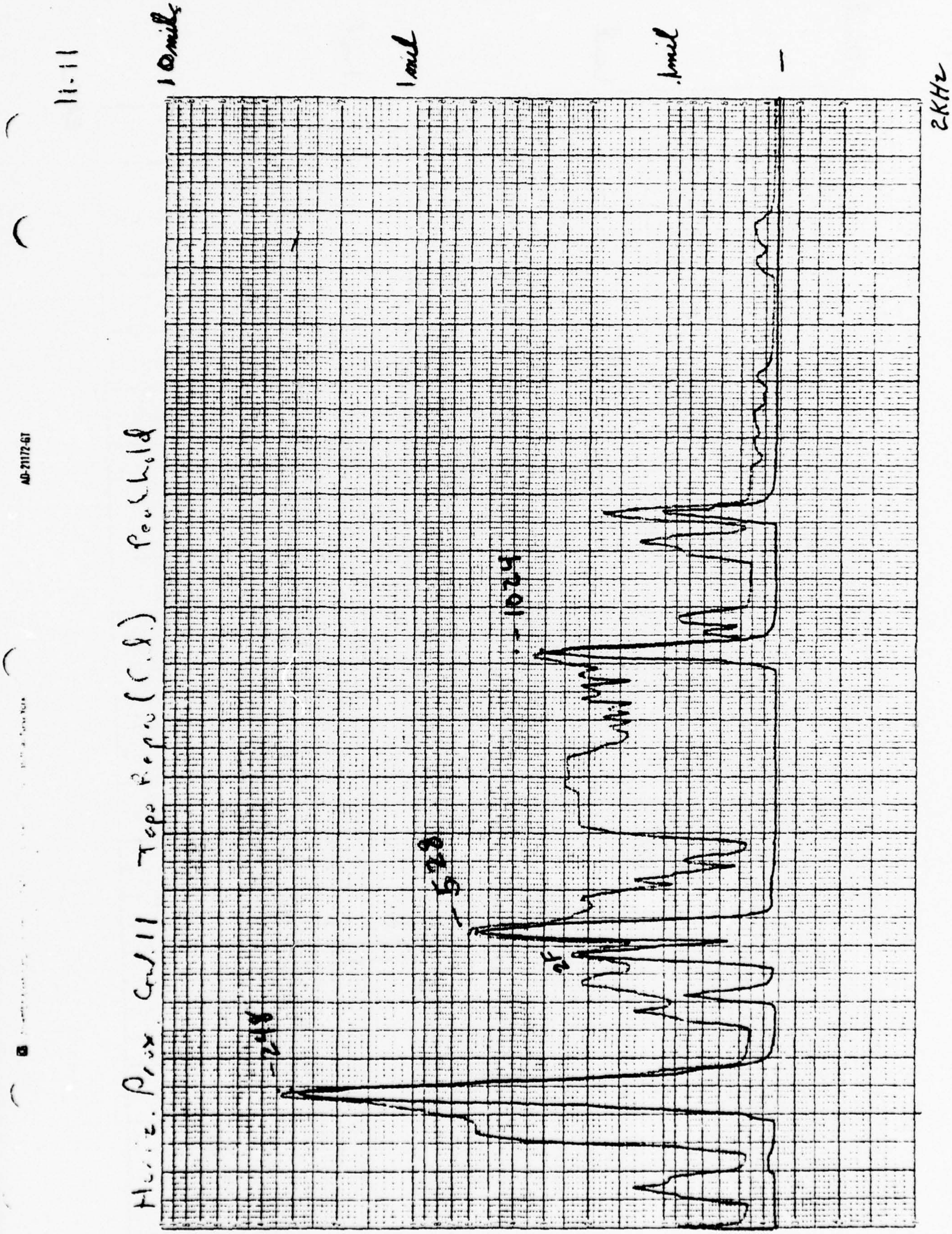


Figure 5b, Sheet 1



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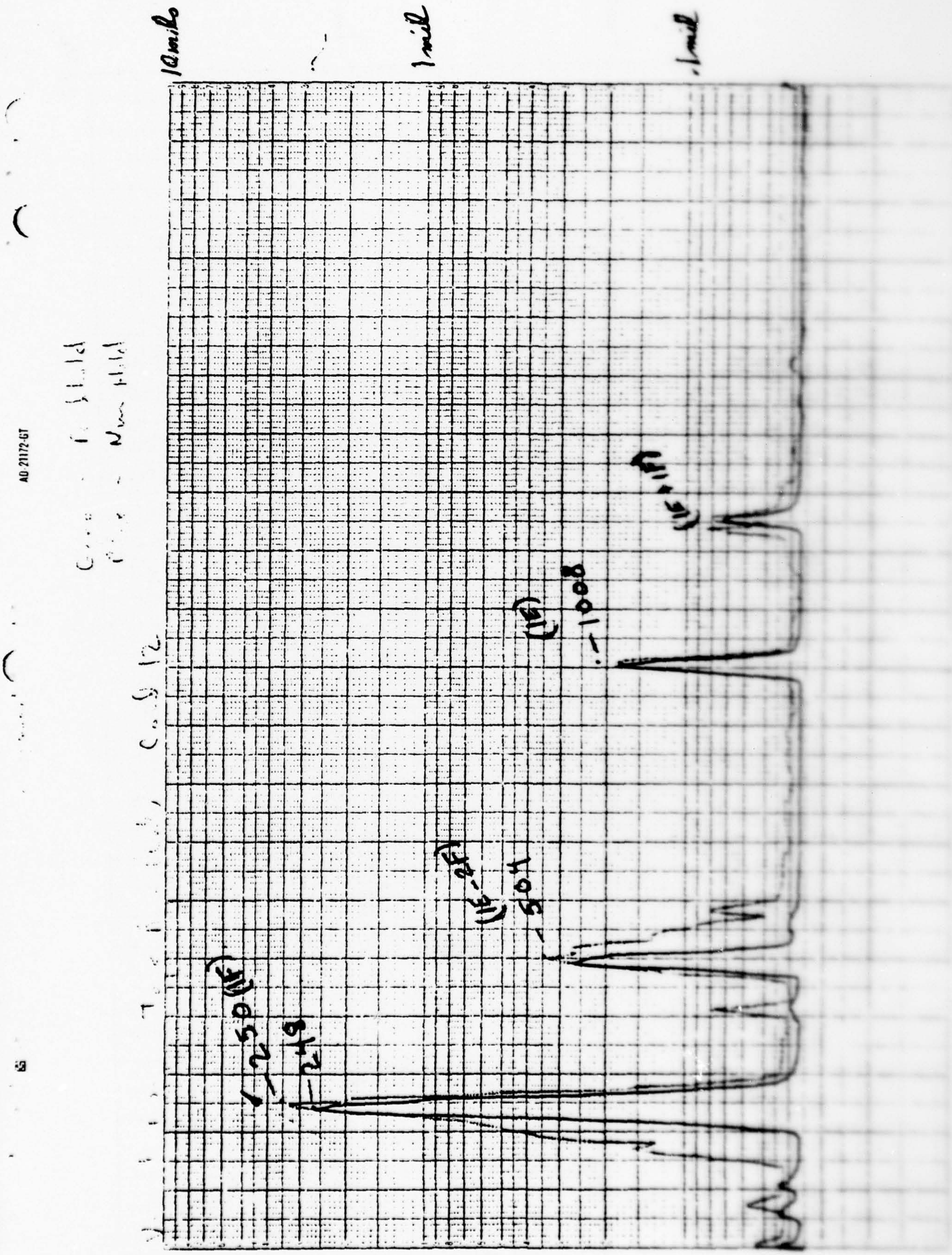


Figure 5c, Sheet 1

11-11

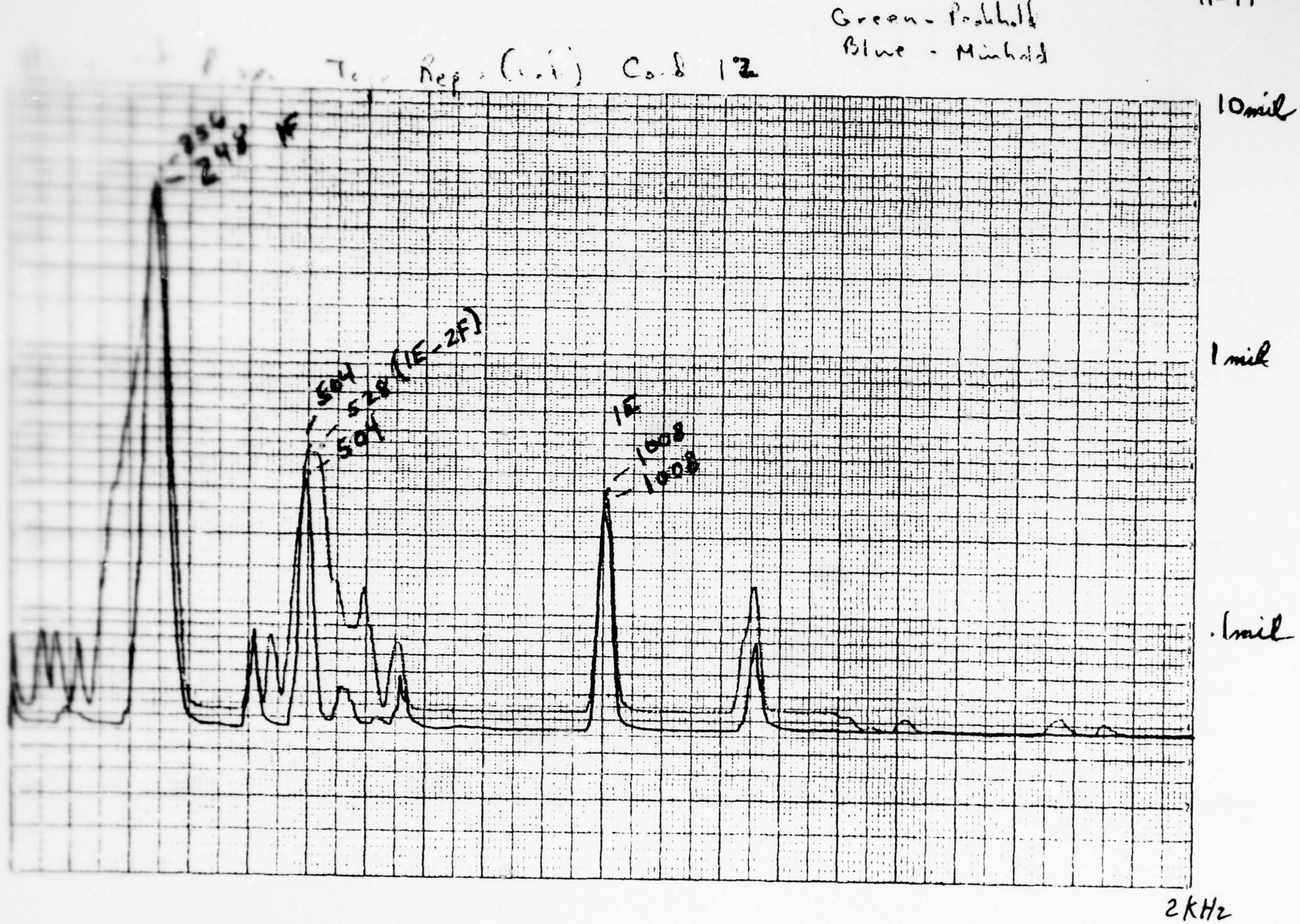


Figure 1e, Sheet 2

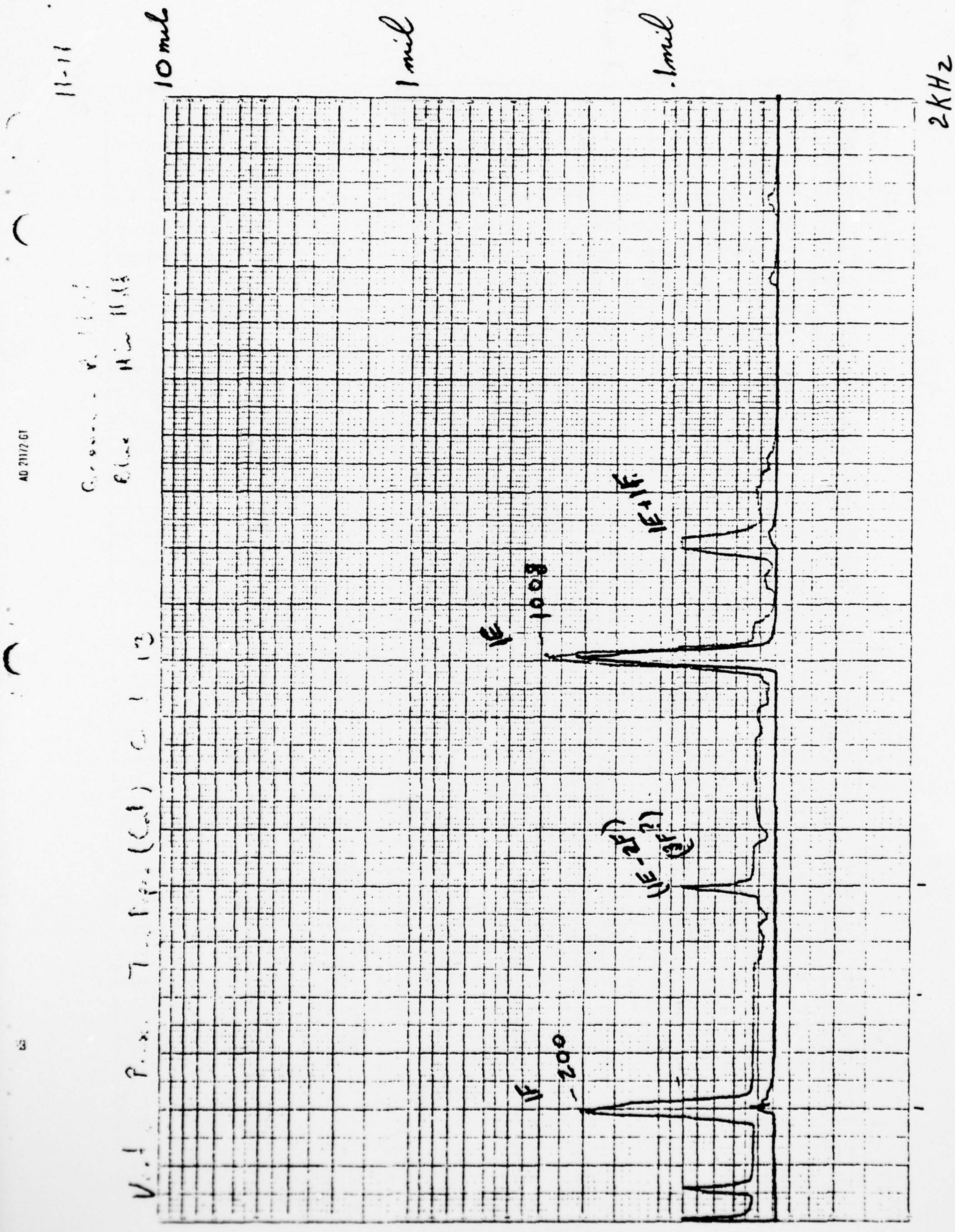


Figure 5d, Sheet 1

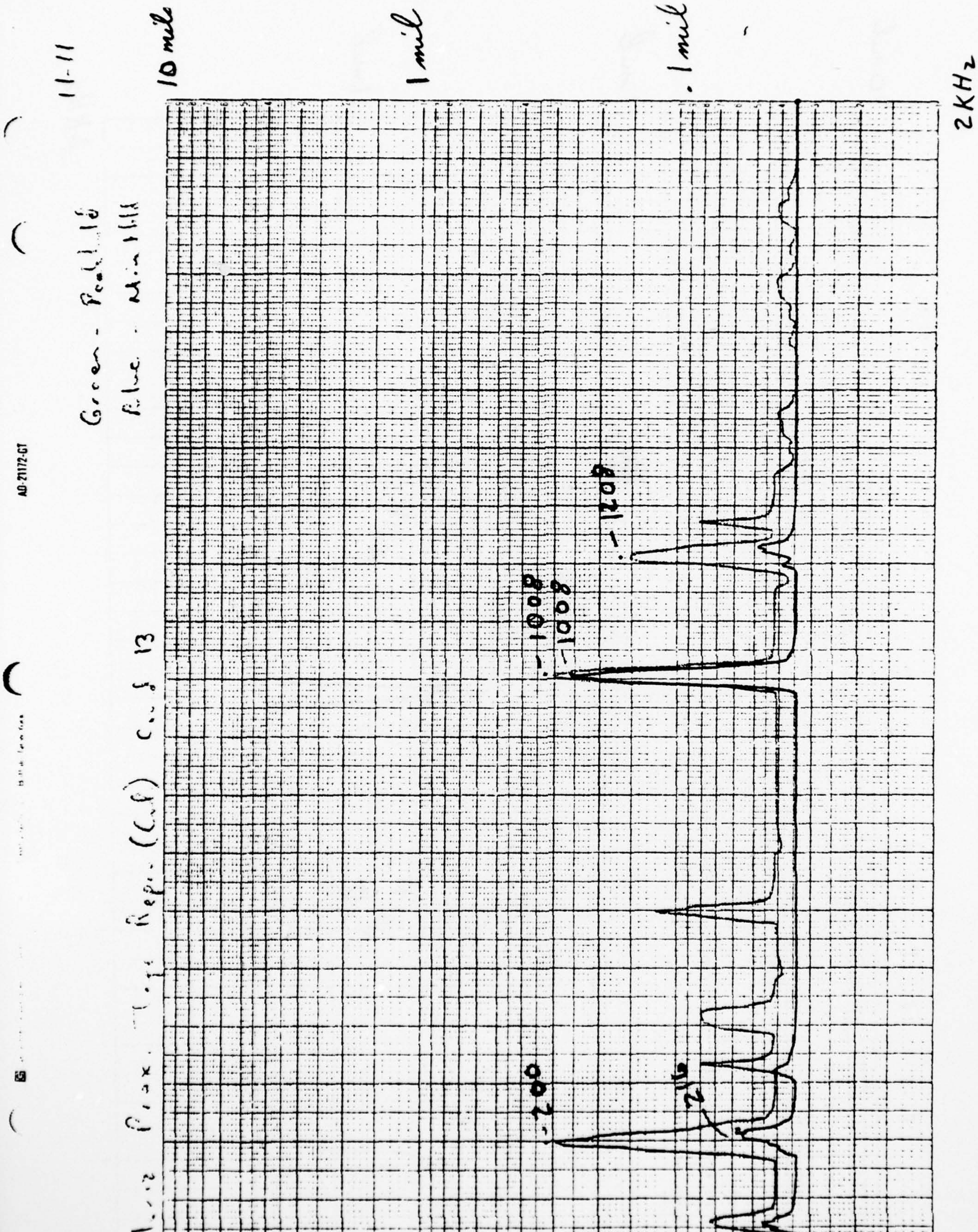


Figure 5d, Sheet 2

APPENDIX C

SECTION 6

ENGINE S/N 70-0097 AT SOLAR
IN EMU-30/E GENERATOR SET

6a - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, No Load, Bellows On, Peak Hold

6b - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, Loaded, Bellows On, Peak Hold

6c - Vertical (Sh. 1) and Horizontal (Sh. 2) Proximity Probes, No Load, Bellows Off, Peak Hold

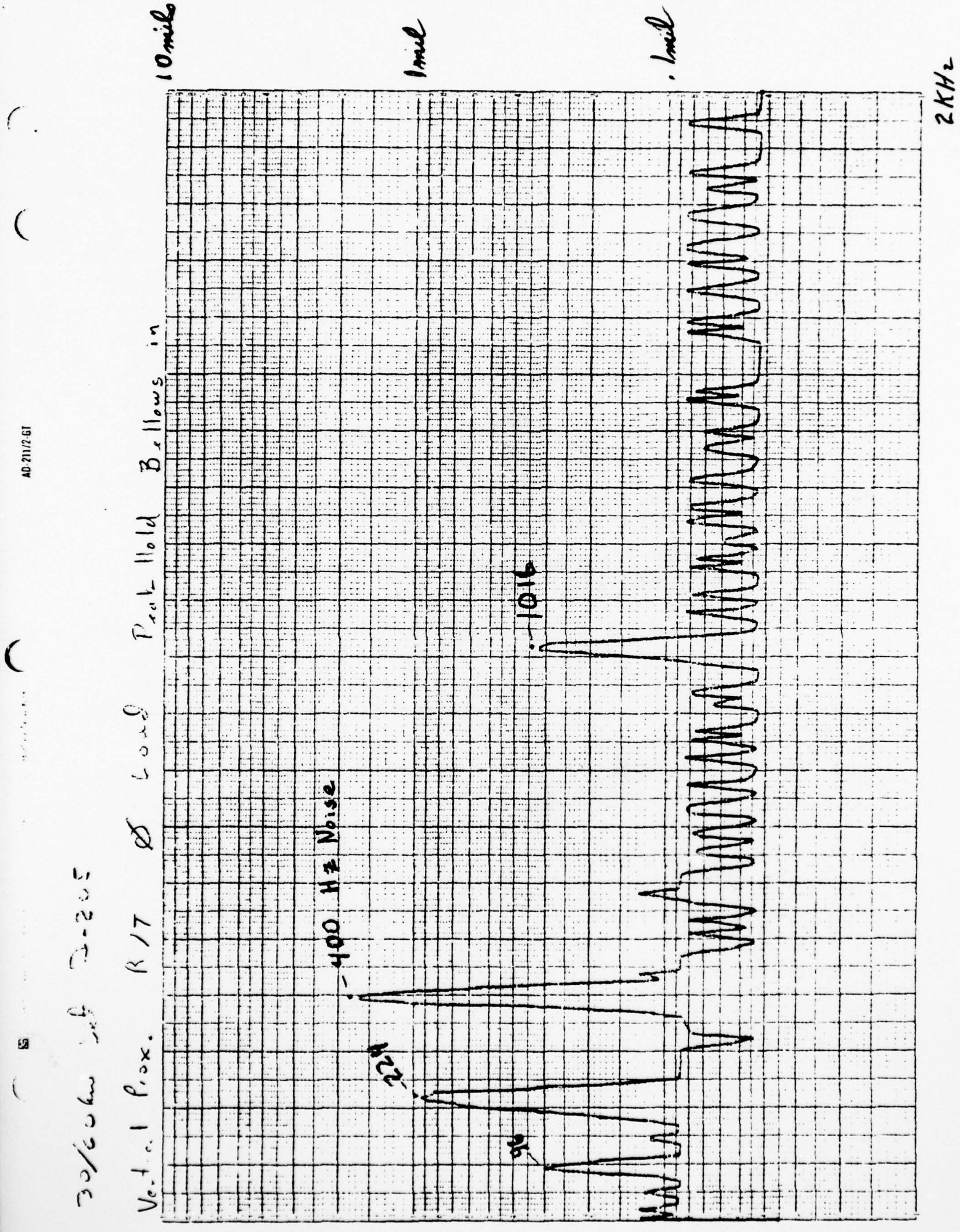
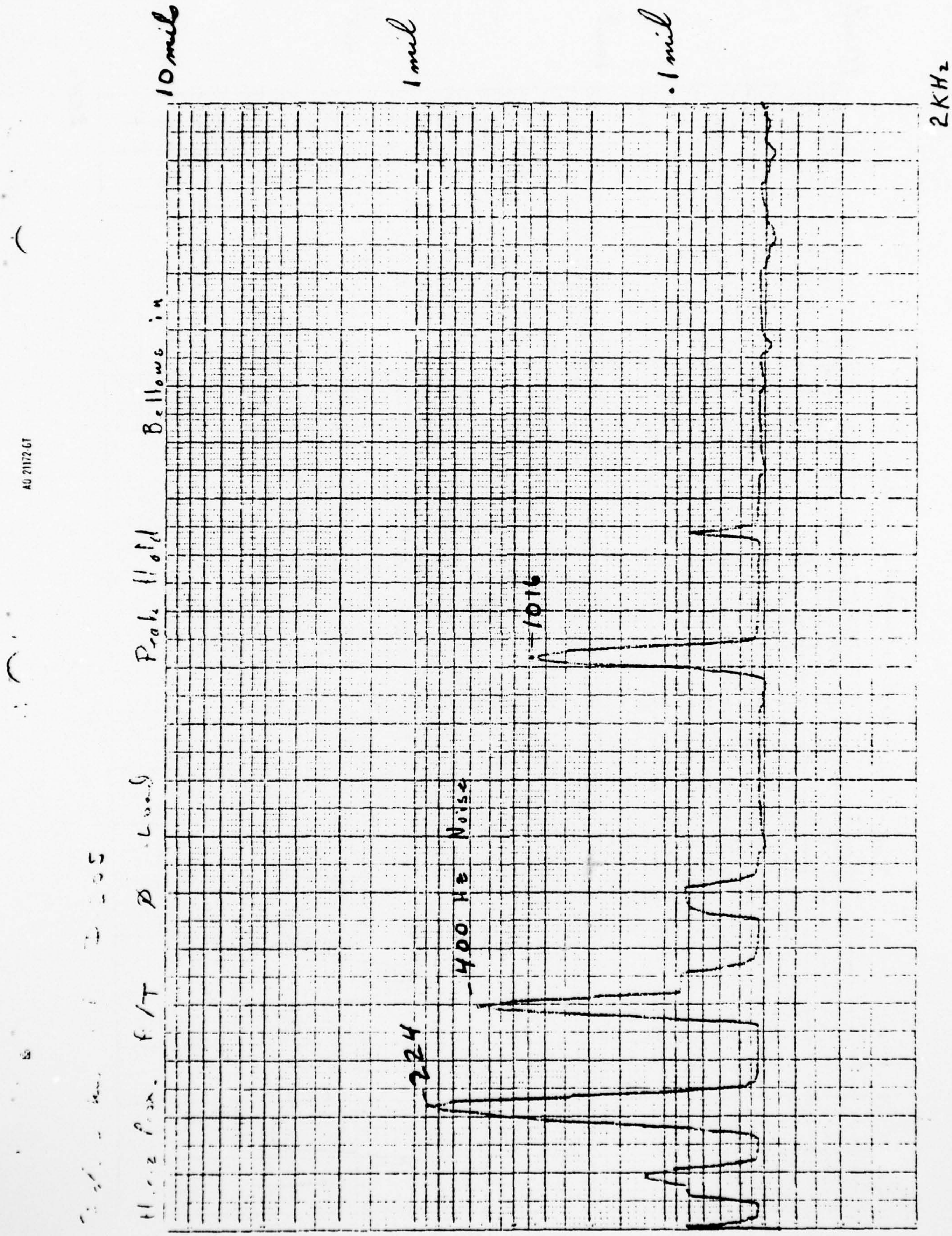


Figure 6a, Sheet 1



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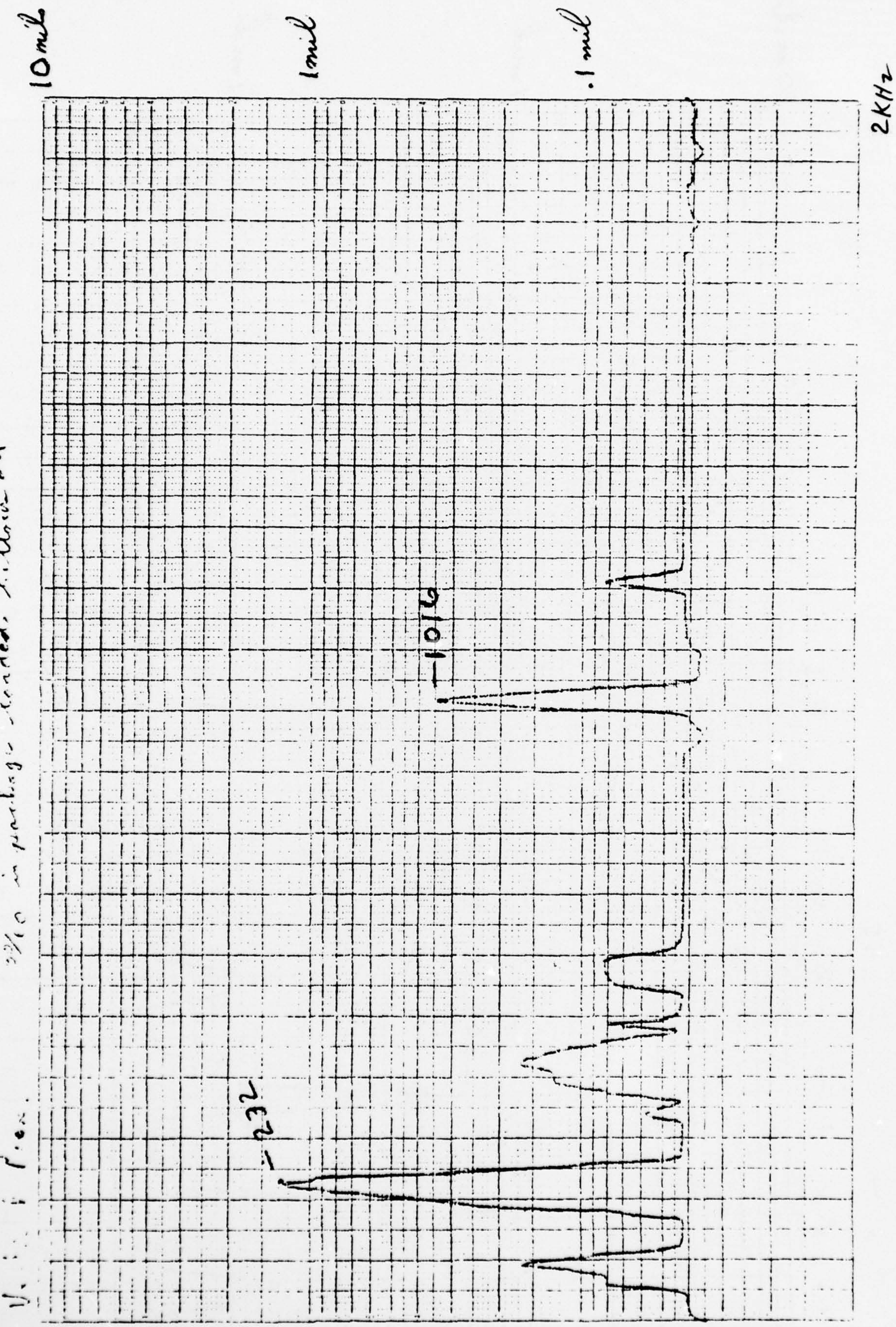

Figure 6b, Sheet 1

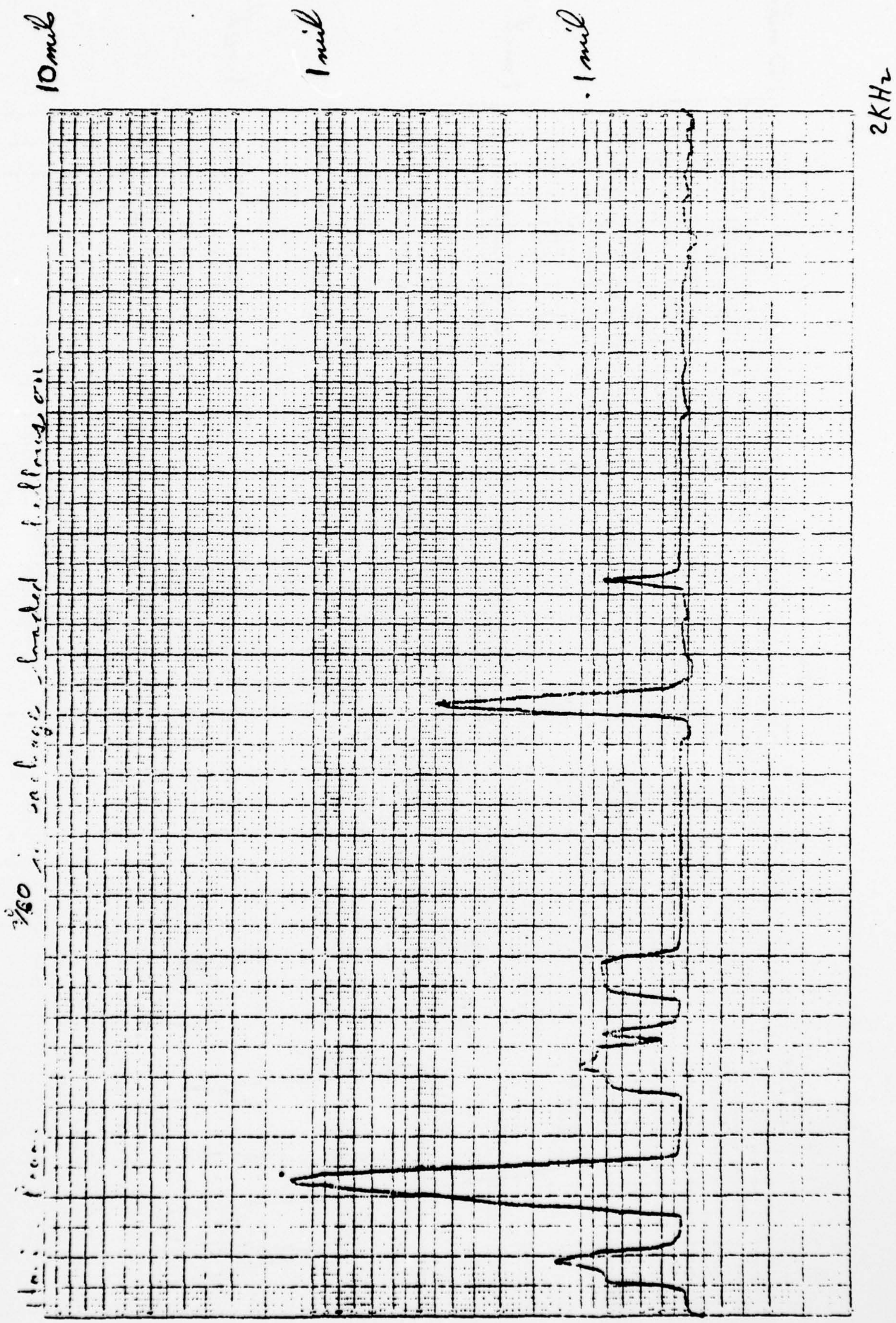

Figure 6b, Sheet 2

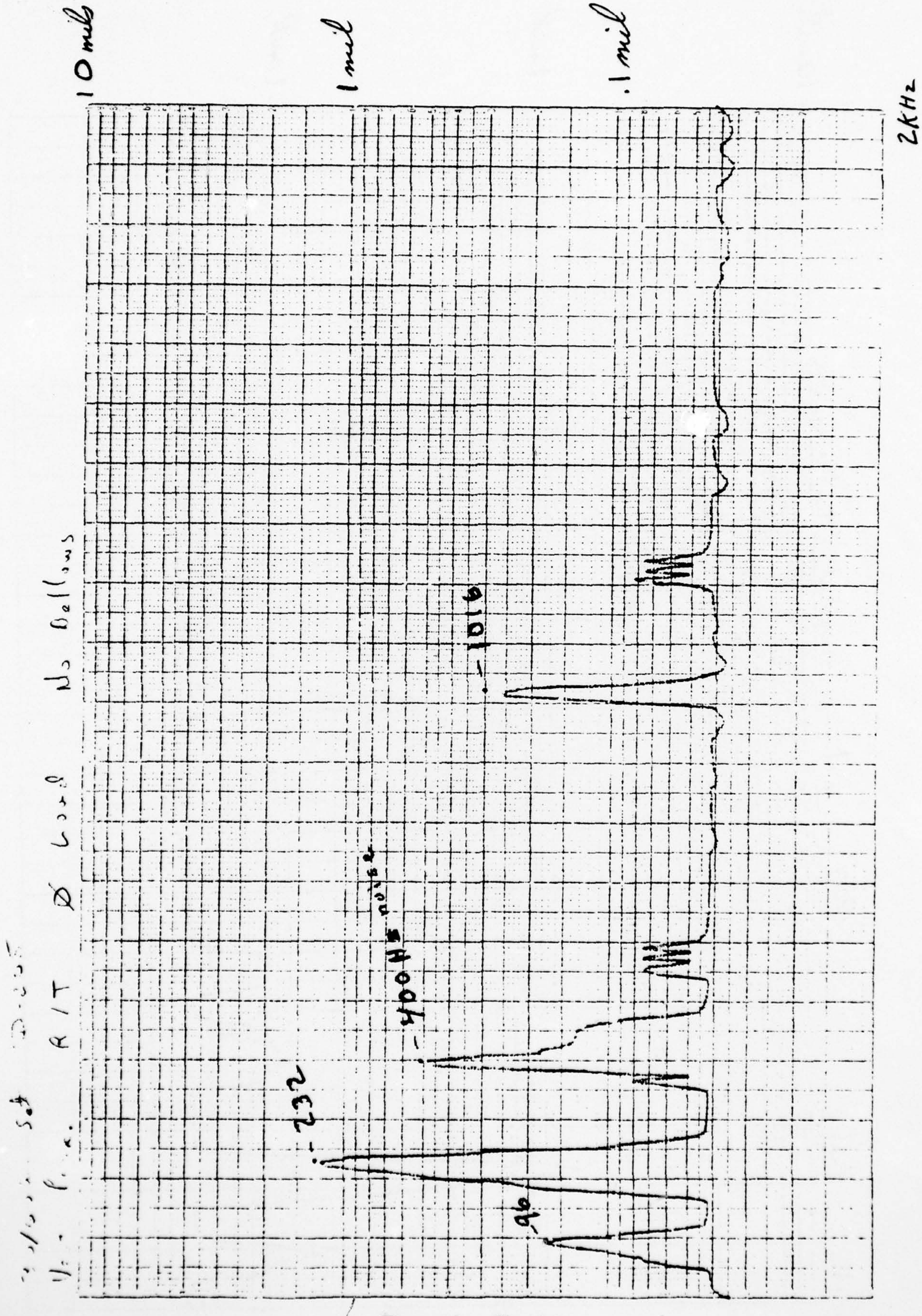

Figure 6c, Sheet 1

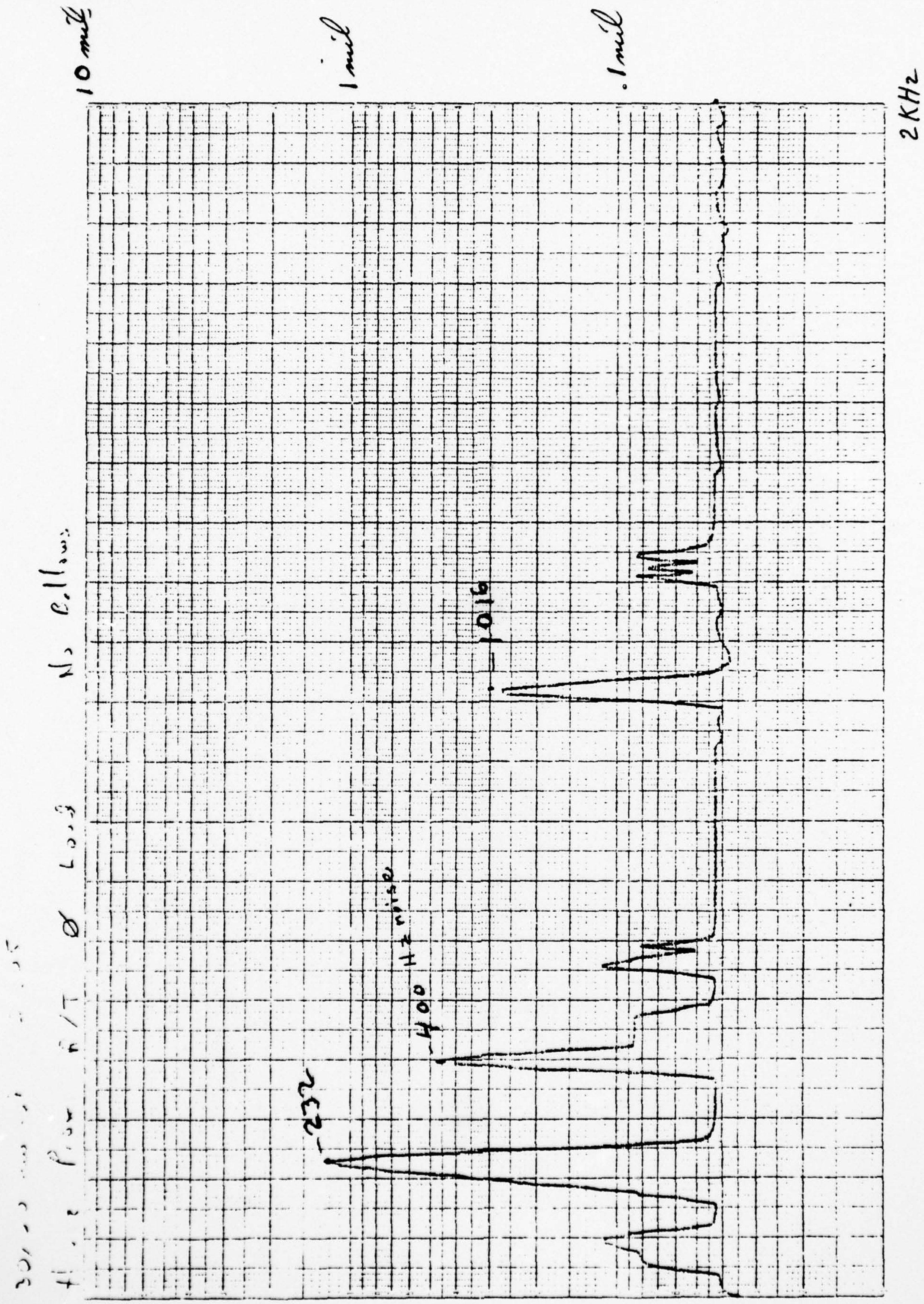

Figure 6c, Sheet 2

APPENDIX D

LACV-30-1 APU STRIPDOWN INVESTIGATION

1.0 INTRODUCTION

Five engine APU failures have recently occurred on LACV-30-1 and LACV-30-2 craft. The last two from craft LACV-30-1 were on a unit which had run satisfactorily for approximately 78 hours and on the replacement unit after approximately 4 minutes. Failures occurred 8/28 and 8/30, respectively.

Both engines and the gearbox to which they are attached were returned to Alturdyne for a stripdown investigation. The identification of the units are as follows:

First failure - Engine S/N 750186
Second failure - Engine S/N 750207B
Gearboxes (in both cases) Solar S/N 105, Alturdyne S/N 1

2.0 OPERATING HISTORY ENGINE S/N 750186 78 HR ENGINE - FT. STORY, VA

2.0.1 The subject engine was installed on craft 001 in May 76 by Bell tech. reps. and Army personnel under the supervision of a Solar technician and Mr. Norm Travis of Alturdyne.

The engine performed successfully with the following noticeable operating abnormalities:

After approximately ? operating hours the engine tripped out on overtemps when attempting starts. Alturdyne was contacted and advised us to make an adjustment on the fuel control unit which was a normal requirement after the above mentioned hours were attained. This adjustment was made and the fault was corrected.

Sometime approaching the 60 to 70 hours time a small amount of engine oil was noticed in the fuel combustion drain line (Pot). It appeared to increase slightly as more hours were accumulated. Alturdyne was notified of this and suggested continued observation but unless it got noticeable in oil consumption to continue to operate.

2.0.2 Around the 78 hour time mark a start was attempted but the engine did not come up to speed and tripped out on high E.G.T. Investigation showed a stiffness in turning the engine over by hand and on rundown considerable rumbling noise was heard. Removal of the engine from the gear box substantiated that there was an internal defect because of stiffness in turning and a thumping noise occurring intermittantly.

2.1 Stripdown Investigation -- Observations

2.1.1 External

2.1.1.1 Fuel manifold was not with the engine. This had been removed at Ft. Story to facilitate engine removal.

2.1.1.2 The pressure casing (outer shell) was observed to have been subject to serve heat -- which resulted in ballooning of the case between the fuel nozzle and the exhaust pipe. Severe surface oxidation was also present. No cause determined at this time.

2.1.1.3 Sheet metal flange (for Marmon clamp attachment) was bent over approximately 60° arc. towards the pressure casing. Cause unknown. Had to be repaired before Marmon clamp could be successfully installed.

2.1.1.4 Engine split and interior of combustion chamber area inspected. Carbon buildup noted on exterior of dome end of combustion liner and on inside of casing corresponding to oxidation on exterior noted in 2.1.1.2. Bleed holes in combustion liner enlarged in certain areas. Two areas were of significant enlargement (one spanning 3 bleed holes).

2.1.1.5 O-ring seals interface between combustion liner and nozzles missing (6 places) Inspection of area indicates that these were never installed. O-ring grooves in all six cases showed no evidence of burnout of ring and were perfectly clean in all cases.

2.1.1.6 O-ring seal at engine split line too large for groove. Evidence of severe extrusion of compound in all directions around the seal length prevent metal to metal contact. O-ring permanently deformed into a cross section equivalent to the groove and face geometry. O-ring material qualities appeared similar to an unaffected O-ring. No evidence of leakage was noted at the split line.

2.1.1.7 Removal of the rotating elements from housing. Cylindrical roller bearing appeared in good condition so did shaft in that area. Compressor blades showed evidence of a hard rub with minor rub indications on turbine where contact with casing had occured. Parts appear salvageable. No evidence of erosion was noted on compressor blades. No evidence of oil was noted on compressor. Ball thrust bearing had cage separation; however, without breaking race open and with bearing still in place balls and race appear to be in good condition. Six of seven rivets clamping cage together had failed. Thrust indicator on bearing toward gearbox. Confirmed by drawing to be correct.

2.1.1.8 The entire inside of the engine casing downstream of the compressor was coated with a gray film. Samples were noted to be soft and in some cases of 'paste' condition. Substance unknown, samples retained for analysis.

3.0 OPERATING HISTORY ENGINE S/N 750207B 4 MIN. ENGINE - - FT. STORY, VA

3.0.1 The engine was received at Ft. Story, VA and installed by Army personnel and a Bell Technician. Installation procedures prescribed by Alturdyne were followed. The gearbox was flushed with new oil and drained and turned over by hand during this process. Visual inspection was made of the Bell air inlet filter and the inlet opening of the engine.

3.0.2 After installation the engine was motored (no fuel) for 30 seconds as prescribed. A start was then made and the engine came up to speed and operated correctly within all prescribed parameters of start time, temperature, and RPM's. Immediately a fuel leak was discovered on one of the fuel nozzle tubing nuts and the engine was secured. The nut was tightened, the fuel cleaned up and another start was made.

3.0.3 The engine again started correctly within all prescribed parameters and ran for approximately 4 minutes. During this time all gauges and the engine itself were being closely monitored. After this run of 4 minutes a rapid fluctuation of E.G.T. was noted and then the E.G.T. started climbing. Before the operator could make a manual shutdown--which he attempted, the unit shutdown on high E.G.T. automatically. Observers at the engine site noted terrible grinding and rumbling noises and smoke issuing from the engine as it quickly ground to a stop. There was no fire started though an extinguisher unit was standing by. Inspection with the unit still installed showed failure of the roller bearing and that contact between the rotor assembly and housing had occurred.

3.1 Stripdown Investigation -- Engine S/N 750207B

3.1.1 Engine still in environmental cases and attached to gearbox on receipt. Inspection of installation indicated some degree of working between rear (vertical) start mount and structure attachment bolt by presence of black oily film on bolt and uniball. Bolt under compressive (downward) load with all equipment attached to engine and gearbox. On removal of starter, bolt was loose and able to be withdrawn with fingers.

3.1.2 Air inlet plenum showned evidence of contact between blanking plug and gearbox and side of plenum. Marking obviously caused during running conditions but on receipt of unit was approximately 3/16 inch above the head of the plug which caused it.

3.1.3 Inspecting intake screen revealed several impact indications at 9 and 11 o'clock looking from exhaust. At least four hits registered at the 11 o'clock position. Some parts of blades found in the screen area. Safety wire locating screen intake with no signs of damage or tampering.

3.1.4 On removal of engine from gearbox it was noted that all nuts appear OK but washers consisted of 8 standard (original?) and 2 stainless steel thin washers and 2 carbon steel cad plated thick washers.

3.1.5 On removal of engine from gearbox the O-ring seal was apparently trapped locally approximately 7 o'clock for approximately 1- 1/2 inches in length. This appeared to have occurred during the installation of the engine.

3.1.6 Load pattern on coast-side of engine output gear indicated contact at extreme ends of teeth, fading to nothing towards the center section of the tooth. Checking with other units available indicated this was typical of units from Solar.

3.1.7 Black oil with some iron particles observed at 6 o'clock position on both engine and gearbox flanges. Traces indicated this to have originated at engine output shaft.

3.1.8 Engine split for internal inspection. O-ring at split line in this case appeared in good condition with no extension and apparently sized correctly (see Paragraph 2.1.1.6).

3.1.9 Internal surfaces of engine heavily coated with aluminum deposit - metallic in appearance. (i.e. no carbon coating). Bond to case very good.

3.1.10 Support tube for cylindrical bearing broken at change in section adjacent to roller bearing seal. Evidence of overheating observed in sun pinion shaft at the splined end. Much damage to labyrinth seal.

3.1.11 Cylindrical roller bearing had frozen (lightly) cage and all rollers were worn down almost to a diameter. Evidence of shaft running on carge was noted by bronze deposits on shaft. Slight scoring noted in local area of bearing on shaft. Much overheating in evidence.

3.1.12 Three struts in air intake showed evidence of impact damage. Two sections indicate metal removal.

3.1.13 Rotating elements and casing -- Compressor severely damaged with portions of blade missing. Not all of these were recovered from the engine. Blades badly bent and broken from hub at root of blades. Two adjacent blades were noted to be bent in the direction of rotation whereas others were bent backwards. Heavy milling action noted on compressor shroud area in both axial and radial planes. Aluminum deposits noted in all rotating element portions. Some milling action noted between turbine and casing. Severe radial rub noted between seal plate assy. and rotor shaft flange. At the fracture line on one blade only, of the longer type, an unnatural discoloration was observed. This had the appearance of rust in the fracture area. No other fracture area on this and another similarily damaged wheel exhibited this feature.

3.1.14 Damage was noted in diffuser section which indicated at least one largish piece of metal had been jammed between the wheel and the diffuser vanes. This item was apparently broken into smaller pieces and there was evidence that these had passed through the diffuser and turning vanes leaving the engine via the combustor liner and exhaust. This implies that they were very small to have accomplished this passage.

3.1.15 No evidence was found at this time of any foreign object which could have precipitated the failure.

3.1.16 At this time oil temperature in operation was considered a possibility in the failure mode. Checks carried out on LACV-30-2 indicate oil temps of not greater than 155°F. This is not considered excessive.

4.0 OPERATING HISTORY OF SOLAR GEARBOX S/N 105 COUPLED WITH ALTURDYNE GEARBOX S/N 1

4.1 The gearboxes were installed in the craft when first built and have remained there since then. At 66 hours an engine failure anticipated to be FOD occurred and the engine was replaced with a new unit. At 89 hours a further engine failure was experienced this time due to a defective ball thrust bearing. At 167 hours the third engine failure occurred which is covered in Section 2.0 of this report - followed some 4 minutes later by the engine failure covered in Section 3.0 of this report. Total time on the gearbox at time of inspection is approximately 167 hours. There were no discrepant operational conditions recorded during this period.

4.2 Strip down of gearboxes Solar S/N 105 and Alturdyne S/N 1.

4.2.1 On removal of the alternator from the gearbox a quantity of oil was observed in the cavity. It was reported that on packaging the engine for shipment the unit was tipped on end (alternator down) and oil was observed to pass through the windings. A coating of grease was observed in the cavity which had been centrifuged out of the spline drive.

AD-A053 566 BELL AEROSPACE TEXTRON BUFFALO N Y F/G 10/2
LACV-30 AUXILIARY POWER UNIT INVESTIGATION.(U)
JUN 77 R P KAISER DAAK02-75-C-0149
UNCLASSIFIED 7467-927024 NL

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4.2.2 A quantity of water with evidence of rust formation was found in the cavity between the fuel control and the gearbox. The gasket appeared to be intact.

4.2.3 Oil contained in gearbox on arrival appeared clear and free of debris. Samples were retained for analysis if necessary.

4.2.4 The Alturdyne gearbox was removed complete and the Solar gearbox was split. A quantity of magnetic chips and fine particles was collected in the sump area and retained for examination. There was no magnetic plug in the sump area.

4.2.5 Observations on gears. -- The planet gear at the 6 o'clock position was noticeably stiffer and noiser when rotated than the other two.

4.2.6 The generator drive gear had some evidence of slight misalignment with its mating gear. However, there was no distress evident.

4.2.7 The oil seal between the gearbox and the alternator was installed (lip flipped) improperly. This was evidenced by the garter spring being out of the lip. Rub marks in the shaft indicated that the shaft had been run in this condition thereby proving that the seal was not damaged during disassembly. This explained the presence of oil in the alternator and cavity observed previously (Paragraph 4.2.1).

4.2.8 The oil filter was removed and found to be free of magnetic particles. The gearbox was spun over by hand and all jets indicated free flow qualities.

4.2.9 Some surface imperfections were noted in the ring gear teeth. Without high magnification it was not possible to determine any significance to these marks.

4.2.10 The vent was removed and the passages inspected. No evidence was found to indicate dirt or dust entry. Passages were free of rust or other corrosion. All internal surfaces were clean with no evidence of corrosion or distress.

4.2.11 Strip down of Alturdyne gearbox S/N 1. On removal of the gearbox from the main box a quantity of rust was observed in the snap ring area. This was caused apparently by water running down between the two gearboxes and being unable to drain away.

4.2.12 The gearbox was split and internal gears appear satisfactory with normal wear pattern. The bearing on the engine side of the output shaft indicated marginal lubrication as evidenced by black deposits on the gear and housing. The bearing was quite free in rotation with no sign of distress.

The foregoing report was compiled on the basis of inputs from the following personnel:

D. Chipchak	Bell Aerospace (New Orleans)
P. Morgante	Bell Aerospace (Niagara Falls)
P. Jackson	Bell Aerospace (Canada)
J. Russell	U.S. Army LACV-30-1-TE
J. Watson	U.S. Army MERADCOM Ft. Belvoir
L. Lester	Solar Engineer (part time) San Diego
N. Travis	Alturdyne, San Diego